BNFL Inc.

Section 3.7

Low Activity Waste Pipe Break

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3.7.1. Work Identification

This section demonstrates an application of the integrated safety management process to an example of Low Activity Waste (LAW) pipe break. This report focuses on the control of hazards associated with the breach of a LAW transfer line between the AP Tank Farm and the pretreatment facility.

As stipulated by the Part B1 contract (DOE-RL 1998), DOE will supply LAW to the TWRS-P Project. DOE will transfer LAW to tank 241-AP-106. Tank 241-AP-106 is an existing million-gallon, double-shell tank located in the AP Tank Farm.

BNFL Inc. is responsible for the transfer of LAW from tank 241-AP-106 to the pretreatment facility, a distance of approximately 3,300 ft (1,000 m). During Part A design, engineering options for containing and routing waste transfers were investigated. The options considered were an above grade, concrete-enclosed pipeduct; a below grade, concrete-enclosed pipe trench; and a below grade, coaxial (i.e., pipe-in-pipe) transfer line. The below grade, coaxial option was selected as the most practical solution (see Section 3.7.1.4). Accordingly, the design concept is to contain and route LAW transfers via two new underground coaxial transfer lines (Table 3.7-6) (BNFL Inc. 1998a and 1998b). **Design Assumption**. Two, new high level waste (HLW) transfer lines will run adjacent to the LAW lines for the majority of their routing.

LAW is a dangerous waste as defined by the Washington State Department of Ecology. The LAW transfer lines must therefore be designed and operated in accordance with applicable regulations promulgated by Washington State Administrative Code (WAC) 173-303, *Dangerous Waste Regulations* (WAC 1995). Associated design and operational requirements are discussed in subsequent sections.

The break of a waste transfer line was selected for analysis because it represents a release external to the facility. A LAW transfer line was selected versus a HLW line because, within the spectrum of the ten examples analyzed, the event was intended to result in medium consequences to the facility and co-located worker and low consequences to the public (see Section 3.0.1). However, as will be shown, a LAW pipe break has the potential to result in high consequences (i.e., SL-1) to the co-located worker. Section 3.7.6.1 presents a discussion of the relative consequences of a HLW versus LAW pipe break.

3.7.1.1. Key Process and Design Parameters

3.7.1.1.1. Process

Specification 7 of DOE-RL (1998) establishes three LAW envelopes, i.e., waste envelopes A, B, and C, based on chemical constituents and radionuclide content. DOE will not transfer non-pretreated envelope B waste to 241-AP-106, and therefore non-pretreated envelope B waste will not be transferred from tank 241-AP-106 via the LAW transfer lines. **Operational Assumption**. The chemical composition and radionuclide content of the soluble fraction of envelopes A and C are shown in and, Table 3.7-1 and

Table 3.7-2 respectively. **Design Assumption**. Values in these tables are given as a function of the sodium concentration, which will range from 3M to 10M per Specification 7. **Design Assumption.**

Table 3.7-1. LAW Chemical Composition, Soluble Fraction Only[1]

Chemical Analyte	Maximum Ratio, Analyte (Mole) to Sodium (Mole)	
	Envelope A	**Envelope C**
Al	2.5×10^{-1}	2.5×10^{-1}
Ba	1.0×10^{-4}	1.0×10^{-4}
Ca	4.0×10^{-2}	4.0×10^{-2}
Cd	4.0×10^{-3}	4.0×10^{-3}
Cl	3.7×10^{-2}	3.7×10^{-2}
Cr	6.9×10^{-3}	6.9×10^{-3}
F	9.1×10^{-2}	9.1×10^{-2}
Fe	1.0×10^{-2}	1.0×10^{-2}
Hf	1.4×10^{-5}	1.4×10^{-5}
K	1.8×10^{-1}	1.8×10^{-1}
La	8.3×10^{-5}	8.3×10^{-5}
Ni	3.0×10^{-3}	3.0×10^{-3}
NO_2	3.8×10^{-1}	3.8×10^{-1}
NO_3	8.0×10^{-1}	8.0×10^{-1}
Pb	6.8×10^{-4}	6.8×10^{-4}
PO_4	3.8×10^{-2}	3.8×10^{-2}
SO_4	1.0×10^{-2}	2.0×10^{-2}
TIC[2]	3.0×10^{-1}	3.0×10^{-1}
TOC[3]	5.0×10^{-1}	5.0×10^{-1}
U	1.2×10^{-3}	1.2×10^{-3}

[1]From DOE-RL 1998

[2]Mole of inorganic carbon atoms/mole sodium

[3]Mole of organic carbon atoms/mole sodium

Table 3.7-2. LAW Radionuclide Content[1], Soluble Fraction Only[2]

Radionuclide	Maximum Ratio, Radionuclide (Bq) to Sodium (Mole)	
	Envelope A	**Envelope C**
TRU[3]	4.8×10^5	3.0×10^6
^{137}Cs	4.3×10^9	4.3×10^9
^{90}Sr	4.4×10^7	8.0×10^8
^{99}Tc	7.1×10^6	7.1×10^6
^{60}Co	6.1×10^4	3.7×10^5
^{154}Eu plus ^{155}Eu	1.2×10^6	4.3×10^6

[1]The activity shall apply to the feed certification date

[2]From DOE-RL 1998

[3]TRU is defined in accordance with 10 CFR Part 61.55

The waste will contain up to 2 weight percent solids (dry basis) per Specification 7. **Design Assumption.** The chemical composition and radionuclide content of the solids is not specified in the Part B1 contract for waste envelopes A, B, or C. For radiological consequence calculation purposes, the radionuclide content of the LAW solids is assumed to be the same as Specification 8 of DOE-RL (1998) for HLW waste envelope D (Elsden 1999). **Design Assumption**. The radionuclide content of envelope D solids is presented in Table 3.7-3. DOE will sample, analyze, and certify that the LAW feed to tank 241-AP-106 complies with Specification 7 requirements. BNFL Inc. will review the waste feed certification documentation and accept the feed prior to transfer (BNFL Inc. 1998c). **Operational Assumption**.

Table 3.7-3. High Level Feed Unwashed Solids Maximum Radionuclide Composition (Curies per 100 grams non-volatile waste oxide)[1,2]

Radionuclide	Maximum (Ci/100 Grams Waste Oxides)
^{3}H	6.5×10^{-5}
^{14}C	6.5×10^{-6}
^{60}Co	1.0×10^{-2}
^{90}Sr	1.0×10^{1}
^{99}Tc	1.5×10^{-2}
^{125}Sb	3.2×10^{-2}
^{126}Sn	1.5×10^{-4}
^{129}I	2.9×10^{-7}
^{137}Cs	1.0×10^{1}
^{152}Eu	4.8×10^{-4}
^{154}Eu	5.2×10^{-2}
^{155}Eu	2.9×10^{-2}
^{233}U	9.0×10^{-7}
^{235}U	2.5×10^{-7}
^{237}Np	7.4×10^{-5}
^{238}Pu	3.5×10^{-4}
^{239}Pu	3.1×10^{-3}
^{241}Pu	2.2×10^{-2}
^{241}Am	9.0×10^{-2}
$^{243,244}Cm$	3.0×10^{-3}

[1]From DOE-RL 1998

[2]Proportion of waste oxides in the solids is approximately 90% by weight (Kummerer 1999).

LAW feed will be transferred at a nominal pressure of 140 psig (10 bar) and a nominal flow rate of 140 gpm (32 m^3/h) to either of two LAW evaporator feed vessels, V12001 and V12002, located in the pretreatment facility (BNFL Inc. 1998a). These vessels have a maximum operating capacity of 60,000 US gal (225 m3). **Design Assumption**. The two vessels will be batch filled and will alternately provide feed to the LAW evaporator. That is, one vessel will be initially filled to provide feed to the evaporator. The second vessel will be filled as required to provide feed to the evaporator as the first vessel approaches its minimum operating capacity. **Operational Assumption**.

The frequency of LAW transfers will be a function of the sodium concentration as the processing rate through the melter is a function of the amount of sodium that can be incorporated into the glass. At 3M Na, it will take 5.8 days to process 60,000 US gal (225 m^3) of LAW at the unenhanced LAW throughput rate of 30 t glass/day (Washer 1999). At 10M Na, it will take 19.4 days. At the enhanced throughput rate of 60 t glass/day, the times to process 60,000 (225 m^3) of 3M and 10M LAW will be 2.9 and 9.7 days, respectively. Enhanced throughput will be provided if agreement with DOE is obtained to treat more waste beyond the nine-year operating phase.

The transfer lines will be flushed with two line volumes of filtered raw water after each use. The transfer lines are flushed in order to: remove waste in the line thereby reducing radiation dose rates, eliminate the need for a compatibility assessment for a subsequent transfer, eliminate solids that may have deposited from a previous transfer thereby avoiding plugging of the line, and enable corrosion control that enhances the reliability of the transfer system.

3.7.1.1.2. Design

The coaxial transfer lines will consist of a 3-inch schedule 40 stainless steel inner pipe and a 6-inch schedule 40 carbon steel outer pipe (BNFL Inc. 1998a). **Design Assumption**. The materials of construction are identical to the recently constructed Hanford Site replacement cross-site transfer system. Pipe supports in the annulus will provide protection against galvanic corrosion. The LAW transfer line materials of construction will comply with WAC-173-303 requirements for compatibility with the process fluid, and will be of sufficient strength and thickness to prevent failure caused by the design basis pressure gradients, climatic conditions, and dead and live loads. The design life of the transfer lines is 40 years, consistent with that of the pretreatment facility (BNFL Inc. 1998b).

The inner and outer pipes of the coaxial design provide primary and secondary containment, respectively, as required by WAC-173-303. **Safety Function**. In addition to provisions for secondary containment, WAC-173-303 requires a leak detection system designed and operated to detect failure of either the primary or secondary containment structure or the presence of any release of dangerous waste or accumulated liquid in the secondary containment. A leak detection system will be provided covering the entire length of the transfer lines (BNFL Inc. 1998a). **Design Assumption, Safety Function**. The leak detection system will be interlocked to automatically de-energize the transfer pump if a leak is detected. **Design Assumption, Safety Function**. As stipulated in *Interface Control Document ICD-19 Between DOE and BNFL Inc. for Low Activity Waste Feed* (BNFL Inc. 1998c), the leak detection system will also be interlocked with the DOE waste transfer controls and leak detection system (i.e., the Hanford Site master pump shutdown system).

The transfer lines will have a continuous slope of at least 0.3% from tank 241-AP-106 to the pretreatment facility such that liquids resulting from leaks to the secondary containment can be removed as required by WAC-173-303.

3.7.1.2. Interfaces

The LAW transfer lines will extend from a new transfer pump pit on tank 241-AP-106. As shown on Figure 3.7-2, valve configurations permit LAW to be pumped by either of two transfer pumps. The pumps will be long shaft centrifugal or turbine pumps with a special purpose, flangeless connection to the transfer lines (BNFL Inc. 1998a). The pumps will be designed to ensure they can not generate a pressure that exceeds the maximum operating pressure of the transfer lines.

A raw water system will provide flush water for the transfer lines. Hanford Site raw water will be stored in a 212-ft^3 (6-m^3) tank located adjacent to the AP Tank Farm. The water will be piped to the new transfer pump pit and connected via valve to the transfer lines.

The primary pipes of the LAW transfers lines will be routed to a valve bulge within the pretreatment facility. From the valve bulge the LAW will be directed to either of two LAW evaporator feed vessels, V12001 and V12002 (Figure 3.7-3). Each vessel has a maximum operating capacity of 60,000 (225 m^3). Instrumentation will be provided for monitoring the liquid level in the evaporator feed vessels during transfers. The secondary pipes of the LAW transfer lines will drain to a collection tank. **Safety Function** (if low point leak detection employed).

3.7.1.3. Operating Environment and Setting

The LAW transfer lines are located within a DOE-mandated corridor selected to minimize interference with roads and other access ways (Figure 3.7-4). The length of the transfer lines from the new pump pit to the pretreatment facility is approximately 3,300 ft (1,000 m). For the majority of the length of the run, the two LAW transfer lines are co-located with two HLW transfer lines.

In order to maintain a continuous 0.3% slope from tank 241-AP-106 to the pretreatment facility, portions of the transfer lines are near or above grade (Figure 3.7-5). Accordingly, approximately 1,480 ft (450 m) of the lines will be bermed.

The elevation of the transfer line at the pretreatment facility is 667.5 ft (203.5 m) above mean sea level (Figure 3.7-5). **Design Assumption**. The maximum elevation of waste in tank 241-AP-106 is 659 ft (200.9 m). **Operating Assumption**. Given these elevations, a siphon external to the pretreatment facility cannot be created that could drain waste from the tank 241-AP-106. **Safety Function**. The elevation of the terminal point within the facility has not yet been determined; the potential for creating a siphon that drains waste internal to the facility will be evaluated during detailed design and appropriate preventive features incorporated as necessary.
Note that the transfer line routings shown in Figures 3.7-4 and 3.7-5 differ slightly. The routing shown in Figure 3.7-4 represents the current design based upon the current plot plan. Figure 3.7-5 reflects the Part A plot plan. Both routings are within the DOE-mandated transfer corridor.

3.7.1.4. Applicable Experience

BNFL has extensive experience transferring highly radioactive liquids between facilities. At Sellafield, transfers between facilities are typically made using pipes contained within concrete pipe bridges or pipe trenches. The piping provides primary containment. The concrete bridges and trenches are lined with stainless steel, which provides secondary containment. The concrete provides radiation shielding. There are typically several pipes located within a single bridge or trench.

Pipe bridges and trenches are used versus underground piping as the distance between facilities is typically relatively short (i.e., hundreds of feet versus thousands of feet). In addition, pipe bridges are used as many transfers are performed by gravity flow.

At the Hanford Site, there is a 40-year history of using underground (either buried or bermed) pipe to transfer highly radioactive liquids between process facilities and tank farms, between tank farms, and between tank farms and waste treatment facilities. Current practice is to use coaxial pipe. The recently constructed Hanford Site replacement cross-site transfer system consists of a 3-in. schedule 40 stainless steel inner pipe and a 6-in. schedule 40 carbon steel outer pipe.

For the LAW transfer lines, a buried coaxial pipe design was selected for application versus a pipe bridge or trench. As will be subsequently shown, the transfer lines must provide containment given a design basis seismic event. Based on the soil characteristics of the Hanford Site, a buried coaxial pipe can be more readily qualified for seismic loads than a concrete trench. Specifically, a long concrete trench with a relatively large cross section would be very stiff and would experience considerable transverse and longitudinal loads given a seismic event. In addition, portions of the transfer route are near or above grade such that the pipes within a concrete trench would be subject to temperature extremes (e.g., temperature variations of 120 °F to –32 °F and a twenty-four hour differential of 52 °F). For a buried pipe, soil provides insulation from temperature extremes. Further, a coaxial design has cost advantages related to the use of an encasement pipe to provide secondary confinement versus lining a concrete trench.

3.7.2. Hazard Evaluation

3.7.2.1. Hazard Identification

The coaxial design of the LAW transfer lines provides primary and secondary containment. Loss of primary containment only, i.e., failure of the 3-inch inner pipe such that LAW leaks to the 6-inch outer pipe, does not present a hazard to co-located workers or the public, as no radioactive material would be released to the environment. Facility workers within the pretreatment facility could potentially receive an external radiation exposure depending on the location and design of the secondary containment collection tank. It is assumed that the tank will be appropriately shielded.

Failure of both the primary and secondary pipes could result in a release of LAW to the surrounding soil. The quantity of LAW released would be a function of the location, size, and spatial orientation of the failures. Conceivable outcomes include:

- A leak of LAW to the soil that remains subsurface. This would pose an external radiation exposure hazard to individuals adjacent to the failure point due to direct shine.

- A leak to the soil below grade that migrates to the surface and forms a pool. The pool of waste would pose both an external radiation exposure hazard and an internal radiation exposure hazard (due to inhalation of airborne radioactive material).

- A leak to the soil at or above grade that erodes a portion of the associated berm and forms a pool. This would pose both an external and internal radiation exposure hazard.

- Formation of a spray release that erodes the soil cover or berm and discharges aerosols of LAW directly to the atmosphere. This would pose both an external and internal radiation exposure hazard.

In addition to potential consequences to the co-located worker and public, a release of LAW to the soil would result in environmental contamination. The release would be reportable to the Washington State Department of Ecology and would require remedial action.

The following subsections analyze failure of the primary and secondary pipes of an LAW transfer line resulting in a pool. A pool scenario was analyzed based on the expectation that it would result in the intended consequences for this example, i.e., medium consequences to the facility worker and co-located worker, and low consequences to the public. Other scenarios associated with transfer line failures and failures within the new pump pit will be evaluated for both LAW and HLW during design development**. Open Issue**.

3.7.2.2. Event Sequence

The event analyzed is a guillotine break of the primary and secondary pipes of a single LAW transfer line. The initiating event is assumed to be an inadvertent excavation performed with mechanical digging equipment (e.g., a backhoe) at the time a transfer is in process. This initiating event was previously identified in the *Hazard Analysis Report* (BNFL Inc. 1997). Other initiating events considered for analysis were: corrosion, erosion, water hammer, dead head pressure, extreme temperature, manufacturing defects, construction defects, subsidence, and natural phenomena hazards. Excavation was selected as the initiating event as it represents an immediate common-cause failure mode for both the primary and secondary pipes. Natural phenomena hazards are discussed in Section 3.7.2.6. Other initiating events will be analyzed during design development to define a comprehensive set of design safety features. **Open Issue**.

Excavations on the Hanford Site are planned and conducted in accordance with established procedures. **Operational Assumption**. Excavation permits (Figure 3.7-6) are required for hand digging to a depth greater than 12 inches and for all excavations by mechanical means (HNF 1997a). Key elements of the excavation permit process include:

- Obtaining or preparing a composite map of the intended excavation identifying existing buried utilities and systems
- Performance of subsurface scans and physical marking of interferences
- Inspection of the proposed excavation job site to physically review and confirm interference field locations and to ensure they coincide with configuration documentation
- Halting work if unidentified field conditions are encountered and obtaining approval of the excavation coordinator and cognizant/project engineer before proceeding.

For this analysis, it is assumed that the permit process is not effective in ensuring that the work area is properly identified, evaluated, and underground interferences marked. As a result, it is assumed that an excavation equipment operator inadvertently arrives at the location of the LAW transfer lines, begins to dig, and causes a guillotine break of a line while a waste transfer is in progress.

As a result of the break, it is assumed that 100% of the LAW flow is out of the transfer line and into, or onto, the ground, resulting in the formation of a pool. No distinction is made as to whether the break occurs in a below grade or bermed portion of the line as, conceptually, no significant, quantitative difference in pool size could be reasoned.

No credit is taken for leak detection. It is assumed that the waste transfer continues for the time normally required to fill one evaporator feed vessel to its maximum operating capacity of 60,000 US gal (225 m^3). Assuming the nominal transfer rate of 140 gpm (32 m^3/h), the transfer continues for 7 hours. Although larger releases can be postulated (conceivably up to the million gallon volume of tank 241-AP-106), the 60,000 (225 m^3) value is judged to be appropriately conservative as the LAW evaporator feed vessels are batch filled one at a time. In the absence of any design safety features, it is a reasonable expectation that operators would, as a routine process control function, periodically monitor the LAW evaporator feed vessel liquid level during filling, observe the anomalous condition, and stop the transfer within the 7 hours assumed. **Operational Assumption.**

3.7.2.3. Unmitigated Consequence

The radiological consequences and associated severity levels (SL) of the event sequence defined above are summarized in the following table.

Unmitigated Dose Consequences[a]

Population	Dose (rem)	Severity Level
Equipment Operator	34	SL-1
Co-located Worker	130	SL-1
Public	0.53	SL-3

[a] See text for dominant pathways

Details of the consequence calculations are documented in Calculation CALC-W375LV-NS-00001 (Kummerer 1999a) and Calculation CALC-W375PT-NS-00003 (Woodruffe 1999).

The dose to the equipment operator is lower than the dose to the co-located worker because the equipment operator is assumed to leave the area within 30 minutes (see item 2 below) whereas the co-located worker exposure duration is taken to be 8 hours per Code of Practice K70P505, *Accident Analysis* (BNFL Inc. 1998e). The dose to the equipment operator is dominated by direct shine. As shown in Kummerer (1999a), the dose due to inhalation of airborne material resuspended from the liquid pool is less than 1% of the dose from direct shine.

The dose to the co-located worker and the public are based on resuspension of radioactive materials. Ninety-six percent of the dose to the co-located worker and the public are due to the solids content of the LAW, the radionuclide composition of which has been conservatively estimated (see item 6, below). Because of the dose contribution from the solids, the severity levels for the co-located worker and public are SL-1 and SL-3, respectively, versus the originally anticipated severity levels of SL-3 and SL-4.

Key assumptions of the calculations are as follows:

1. Location of the Equipment Operator. The equipment operator is assumed to be located at the edge of the resultant waste pool. Given the assumed failure to effectively implement the Hanford Site excavation permit process, no basis could be derived for assuming the equipment operator would recognize the waste pool as a hazard and immediately evacuate.

2. Equipment Operator Exposure Duration. The exposure of the excavation equipment operator is dominated by external radiation exposure, i.e., shine from the pool. The dose rate is approximately 1.1 rem/min (Woodruffe 1999). Consideration was given to an exposure duration ranging from 10 minutes to 8 hours. A 30-minute duration is assumed based on the expectation that the operator would observe the pool and contact either his supervisor or the responsible person-in-charge and be directed to leave the area within a 30-minute time period.

   To assist in establishing the exposure duration for the equipment operator, a sensitivity study was performed to examine the change in dose rate as a function of pool size. It was found that the dose rate at the edge of the pool is relatively insensitive to pool size. The dose rate from a pool 26 ft (8 m) in radius (equivalent to approximately 10 minutes of pumping) is 0.97 rem/min while the dose rate from a pool 46 (14 m) in radius (equivalent to approximately 30 minutes of pumping) is 1.1 rem (Woodruffe 1999).

3. Facility Worker Exposure Duration. For the event sequence analyzed, no facility worker is present as the event occurs outside of BNFL Inc. facilities. If present, the facility worker would recognize the hazard based on facility specific training and would evacuate himself and the equipment operator. **Operational Assumption**. The probability of failing to evacuate within 10 minutes is considered negligible. If present for 10 minutes, the resultant dose would be 11 rem, yielding a severity level of SL-2.

4. Pool Area. The size of the pool formed by the release of 60,000 US gal (225 m^3) is dependent on several factors including: the leak flow rate, the topography of the leak site, the infiltration rate into the soil, the salt content of the waste, the temperature of the waste, and the ambient temperature. It is assumed that the average area of the pool is 13,500 ft (1,255 m^2). This area was used to model the consequences of a leak from an unencased, bermed waste transfer line in the *Tank Waste Remediation System Basis for Interim Operation* (HNF 1997b) and is based on the dimensions of an actual pool formed when raw water overflowed a service pit.

5. Release Fractions. The 60,000 US gal (225 m^3) of waste is assumed to form a pool over the 7 hours that the transfer pump is operating. During this time, the co-located worker at 328 ft (100 m) and the public are exposed via wind-induced resuspension from the surface of the pool. After the pump has stopped, it is assumed that the liquid soaks into the ground and the receptors are exposed via resuspension of contaminated soil.

   The resuspension flux from the pool is 2×10^{-10} kg/m^2s. This value, from *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, (DOE 1994), corresponds to the mass release for a pond with a 656 ft (200 m) fetch at wind speeds of less than 5 m/s. The respirable fraction of the material resuspended from the pool is 1.0. The resuspension flux from DOE (1994) is comparable to the resuspension flux of 10 mg/m^2 d (1.16×10^{-10} kg/m^2s) given by the Sellafield database for windspeeds of 1 to 5 m/s.

   The respirable release fraction from contaminated soil is 8.4×10^{-5} over 24 hours. This value, from DOE (1994), is based on experiments with uranyl nitrate nonahydrate solutions spilled on soil and dried under low wind speed conditions (i.e., <2.5 mph). A comparable value of 1×10^{-9}/s (8.6×10^{-5}/d) is given by the Sellafield database as the aerosol release rate from spills on sandy soil for air velocities of 1 m/s.

6. Source Term. The concentrations of soluble radionuclides in the waste are based on envelope C waste at 10M Na. Enveloped C was selected because the concentration of transuranic radionuclides (which are the dominant contributors of the inhalation dose) is higher than envelope A, and because non-pretreated envelope B will not be transferred via the LAW transfer lines.

7. The LAW is assumed to contain the maximum 2 weight percent solids allowed per Specification 7. The radionuclide content of the solids is based on high level waste envelope D as no data for solids was provided for LAW envelopes (refer to Section 3.7.1.1.1).

8. Skyshine. The dose due to skyshine to the equipment operator and the co-located worker is assumed to be negligible relative to the doses from direct shine and inhalation. Calculations documented in *Calculation Note for Subsurface Leak Resulting in a Pool, TWRS FSAR Accident Analysis*

(WHC 1996a) show that skyshine can account for 7% of the total dose at 328 ft (100 m). **Open Issue**.

The chemical hazards associated with a release of 60,000 US gal (225 m^3) of LAW were not determined. A method for determining toxicological consequences will be derived during design development. **Open Issue**.

3.7.2.4. Frequency of the Initiating Event

The initiating event for the analyzed scenario is an inadvertent excavation activity using mechanical digging equipment that results in a guillotine break of the primary and secondary pipes of a single LAW transfer line. The frequency of this event is conservatively estimated to be 5 x 10^{-4}/yr. As discussed in the following paragraphs, this estimate is based on three factors: human error associated with the work planning process, the likelihood that the excavation equipment is capable of rupturing two schedule 40 pipes, and the likelihood that the excavation occurs at the location of the LAW transfer lines when a transfer is in progress.

The frequency of the initiating event is estimated assuming two initial conditions. First, it is assumed that access control of the Hanford Site is maintained. **Operational Assumption**. Currently, access control is provided at the Wye and Yakima Barricades. By crediting access control, it can be assumed that only excavation equipment operators tasked to perform a specific activity are present on the Hanford Site. Second, it is assumed that the Hanford Site excavation permit process, as administered by Fluor Daniel Hanford, Inc. and Bechtel Hanford, Inc. is in place and maintained. **Operational Assumption**. The frequency of failing to effectively implement the excavation permit process such that an equipment operator arrives on the Hanford Site and begins to dig without confirming the proper location of the activity and with disregard for potential underground interferences is estimated to be 5 x 10^{-1}/y. This estimate is based on an assumed 500 excavations/y and a human error probability of 1 x 10^{-3}/demand. The 500 excavations/y value is an order-of-magnitude assumption and is based on discussions with the Hanford Site excavation permit coordinator who reports that from 300 to 400 excavation permits per year have been processed over the last two years. The 1 x 10^{-3}/demand value is based on human error probabilities associated with failing to comply with a plant policy requiring strict adherence, record keeping, and related review and controls (Kolaczkowski 1999).

The probability that the equipment operator is utilizing excavation equipment of sufficient size to breach the transfer lines is assumed to be 1 x 10^{-1} (i.e., one in ten excavations is performed with equipment sufficient to break the pipes). This assumption is based on an engineering study of the stress on primary and secondary piping due to loads provided by backhoes (WHC 1996b). The study concluded that the load imparted by an average size, wheeled backhoe does not exceed code allowable stress on 6-in and 3-in diameter, schedule 40 pipes. There is no known data regarding the frequency with which average size, wheeled backhoes are used relative to larger excavating equipment at the Hanford Site. A value of 1 x 10^{-1} is judged to be reasonable approximation. Intuitively, there is a correlation between the size of the excavation to be performed (and thus the size of equipment used) and the probability of effectively implementing the permit process. Specifically, the larger the excavation, the greater the likelihood that the permit process will be entered into and properly followed. This correlation represents an unquantified conservatism in the overall frequency estimate.

The probability that the equipment operator arrives at the specific location of the LAW transfer lines when a transfer is in progress is estimated to be 1 x 10^{-2}. This estimate considers two factors. First, the Hanford Site encompasses a very large area, approximately 580 mi^2 (1500 km^2). Within this area, activities are concentrated in a number of smaller areas (e.g., 200 West Area, 200 East Area, 400 Area, etc.). The 200 East Area, where the AP tank farm is located, is 3.6 mi^2 (9.4 km^2) in area. The area of the transfer lines is on the order of 0.77 mi^2 (2,000 m^2), assuming a length of 3,300 ft (1,000 m) and a width-at-risk of 6.5 ft (2 m). Although not quantified, the probability that the equipment operator arrives at the location of the transfer lines versus some other location on the Hanford Site is judged to be low. Second, transfers are conducted on a periodic versus continuous basis. The highest transfer frequency is once every 3 days (3M Na, 60 t/d throughput). The lowest transfer frequency is once every 20 days (10M Na, 30 t/d throughput). The probability of a transfer being in progress on any given day over the course of a year therefore ranges from 3.3×10^{-1} to 5×10^{-2}. Considering both factors, the 1×10^{-2} estimate is judged to be conservative.

Combining the above frequency and probability estimates yields the estimated frequency of the initiating event, i.e., $(5 \times 10^{-1}/y) \times (1 \times 10^{-1}) \times (1 \times 10^{-2}) = 5 \times 10^{-4}/y$. The validity of this estimate can be inferred from reliability databases. The Sellafield database (BNF plc. 1998) predicts a general failure rate of buried stainless steel pipelines of 1×10^{-7}/m/y. This failure frequency is dominated by corrosion and external man-made events (e.g., digging). Applying the Sellafield data to an LAW transfer line with a length of 3,300 ft (1,000 m) yields a failure frequency of 1×10^{-4}/y. The Savannah River site database (WSRC 1993) recommends a failure rate of 1×10^{-10}/hr/ft for the complete rupture of a pipeline. Applying this value to an LAW transfer line and assuming the highest transfer frequency (i.e., every 2.9 days based on 3M Na, 60 t/d throughput) yields a failure frequency of 2.6×10^{-4}/y. Accordingly, the 5×10^{-4}/y value derived for the initiating event frequency is judged to be a reasonable estimate, as it approximates the values established by the two referenced databases.

3.7.2.5. Common Cause and Common Mode Effects

No common cause or common mode effects other than natural phenomena and man made external events were identified as being likely contributors to the accident frequency.

3.7.2.6. Natural Hazards and Man-Made External Events

3.7.2.6.1. Natural Phenomena

As discussed in Section 2.10, natural phenomena potentially impacting LAW transfer line safety functions include seismic, high wind, wind-generated missiles, flood, snowfall and volcanic ash, and temperature extremes (BNFL Inc. 1998d). A seismic event represents a common cause failure mode for both the primary and secondary pipes. High wind or the design basis precipitation could conceivably erode portions of the berm and weaken the transfer line foundation, which in turn could lead to structural failure of the lines. Portions of the LAW transfer lines are above grade and, although bermed, are potentially vulnerable to wind generated missiles. Snowfall and volcanic ash represent loads for which the transfer lines must be designed.

3.7.2.6.2. Man-Made External Events

The LAW transfer lines extend for 3,300 ft (1,000 m) from the AP Tank Farm to the pretreatment facility and are thus vulnerable to external man-made events. Specifically, the event sequence analyzed above (i.e., inadvertent excavation) is a man-made external event. In addition, the transfer lines are vulnerable to aircraft crash.

3.7.3. Control Strategy Development

As stated in Section 3.7.1, because LAW is classified as a dangerous waste as defined by the Washington State Department of Ecology, the LAW transfer lines must be designed and operated in accordance with the requirements of WAC-173-303. These requirements are therefore credited as an inherent part of the control strategy.

3.7.3.1. Controls Considered

In developing a control strategy for a guillotine break of an LAW transfer line due to inadvertent excavation activities, both preventive and mitigative controls were considered.

Preventive controls reduce the frequency at which the event will occur. The preventive controls considered are as follows:

- BNFL Inc. Excavation Permit. The event sequence analyzed in Section 3.7.2.2 assumes as an initial condition of the analysis that the Hanford Site excavation permit process, as administered by Fluor Daniel Hanford, Inc. and Bechtel Hanford, Inc. is in place and maintained. This assumption addresses excavation activities by these companies and their subcontractors. For the analysis to remain valid, BNFL Inc. must establish and maintain an equivalent or superior permitting process. Refer to Section 3.7.2.4 for a listing of key elements of the permit process.

- Postings. This control consists of a series of signposts and postings that physically mark the transfer line route and alert individuals to the presence of an underground radioactive waste transfer line. The signposts could also state that no excavations are permitted within some specified distance from the posts without first contacting BNFL Inc.

- Access Control Fencing. This control consists of a fence with locked access that runs along both sides of the transfer route at some distance determined to be sufficient to preclude potential damage to the transfer lines. Current Hanford Site tank farm controls allow only hand digging within 5 ft of a waste transfer line, and all excavations are prohibited within 15 ft of an ongoing waste transfer.

- Chain or Rope. A chain or rope could be used in conjunction with signposts to more clearly identify the transfer line routing.

- Surface Concrete Slab. A concrete slab poured over the surface of the ground along the transfer line route would provide a physical barrier to excavation.

- Subsurface Concrete Slab. A subsurface concrete slab running along the transfer line route would provide a physical barrier to excavation and an indication of subsurface interferences. Such concrete is typically dyed red in color for application to subsurface electrical conduit.

- Jersey Barriers. Jersey barriers are elongated concrete blocks. Placing a series of these blocks on the ground along the transfer line route would provide a physical barrier to excavation.

- Subsurface Steel Mesh. A subsurface steel mesh could be placed over the transfer line routing. Such a mesh would indicate the presence of subsurface interferences to a trained equipment operator and could serve as a physical barrier to excavation.

- Subsurface Cable or Tape. Similar to the subsurface steel mesh, a subsurface cable or tape would indicate the presence of subsurface interferences to a trained equipment operator. The Hanford Site replacement cross-site transfer line uses a 6-in. wide plastic tape buried 1 ft below the ground surface (HNF 1997a).

- Subsurface Multi-conductor Cable. A subsurface cable over the transfer route could be electrified and instrumented to alert BNFL Inc. personnel given interruption of the circuit. Such a cable would have a two purposes. First, it would indicate the presence of subsurface interferences to a trained equipment operator thereby potentially preventing a line breach. Second, operator response could be to stop the transfer thereby mitigating the event given a breach were to occur.

- Operator Surveillance. Operators could perform periodic surveillance of the transfer route to ensure that no inappropriate activities were being conducted.

- Video Surveillance. Video cameras could be strategically placed along the transfer route and monitored by operators to ensure that no inappropriate activities were being conducted.

Mitigative controls reduce the consequences of an event. The following two mitigative controls were considered:

- Leak Detection. Leak detection is required by WAC-173-303. Leak detection mitigates the event by triggering the shut down of the transfer thereby reducing the volume of waste leaked. Reducing the volume of the leak reduces the quantity of radionuclides potentially entrained by the wind and transported downwind to the co-located worker and public receptors. The following leak detection methods were considered:

  a. Low point leak detection. This method uses gravity to drain liquids leaked from the primary pipe into the secondary pipe to a collection point where they are detected by instrumentation (e.g., conductivity probes or pneumercators).

  b. Continuous leak detection cable. This method uses a leak detection cable placed in the annulus between the primary and secondary pipes to detect leaks at any point along the length of the run.

  c. High-pressure secondary. This method pressurizes the secondary pipe with a gas (e.g., nitrogen) to approximately 1.5 times the primary pipe operating pressure. A drop in pressure would indicate a potential failure of the primary or secondary pipe.

  d. Low-pressure secondary. This method pressurizes the secondary pipe to a pressure lower than the primary but higher than ambient. A drop in pressure would indicate a potential failure of the secondary pipe.

  e. Depression monitoring. This method draws and holds a vacuum on the secondary pipe. A drop in vacuum would indicate a potential failure of the secondary pipe.

  f. Receipt tank level monitoring. This method measures and indicates the liquid level within the receipt tank. A static or very slowly increasing liquid level during a transfer would be indicative of a potential system leak.

g. Differential flow rate. This method uses flow rate meters at each end of the transfer line to measure and compare the flow rate. Algorithms are derived to compare the flow rates and detect significant differences.

- Emergency Response. Given an indication that a potential leak has occurred, the following emergency response actions were considered:

  a. Stop transfer. Stopping the transfer reduces the volume of waste leaked, which in turn reduces the potential consequences of the event. If leak detection systems automatically stop the transfer, the operator action would be to verify that the transfer pump is de-energized. This activity provides an additional layer of defense in depth. If the automatic system failed, manual actions could be taken to stop the transfer.

  b. Survey the transfer route. The purpose of surveying the transfer route on indication of a leak is to visually determine if a leak has occurred and to evacuate personnel from the immediate area as necessary.

  c. Spill response. The consequences of a spill can be mitigated by taking actions that prevent or reduce the resuspension of hazardous materials. Such actions can be as simple as maintaining a wetted surface.

3.7.3.2. Control Strategy Selection

Control strategy selection was based on a two-step process: first, clearly unrealistic control elements were deleted; second, engineering tradeoffs were considered to further down-select the options, and a preferred control strategy was selected.

3.7.3.2.1. Step 1 (Initial Screen)

The merits of each of the potential controls described above were considered, primarily against the following set of criteria.

- Effectiveness
- Practicability
- Reliability
- Demonstrability
- Compliance with laws and regulations
- Ability to comply with DOE/RL-96-0006, *General Radiological and Nuclear Safety Principles* (in particular, use of proven engineering practice, ease of providing inherent/passive safety features, radiation protection features, and avoidance of undue reliance on human actions).

The objective of the initial screen is to identify the main advantages and disadvantages of each control, and also to eliminate those that are not considered viable in formulating a composite control strategy.

Table 3.7-4 presents the evaluation of preventive controls to the above criteria. Table 3.7-5 presents the evaluation for the identified methods of leak detection. An evaluation of emergency response actions was not performed. Emergency response action plans will be developed prior to facility operation, but are not being relied upon to demonstrate risk acceptability during design.

Of the 17 controls evaluated in Table 3.7-4 and Table 3.7-5, only one, the use of a chain or rope as a preventive measure against inadvertent excavation, was screened from further evaluation. Although chains and ropes are commonly used for restricting access, they are judged to be of marginal effectiveness based on the ease with which they can be circumvented by personnel not specifically trained as to their meaning.

Table 3.7-4. Initial Evaluation of Preventive Controls

Control Strategy	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
BNFL Inc. Excavation Permit Process	Use of excavation permits is a standard Hanford Site practice Ensures that subsurface interferences are identified and physically marked Easily demonstrated via written procedures and performance records	Partially effective based on failure to obtain permit or failure to comply with permit stipulations	Proven administrative practice used by all Hanford Site contractors Active control versus passive Reliant on human intervention	Yes
Postings	Easily implemented Effective if observed by trained personnel Postings can explicitly warn of hazard Easily demonstrated via surveys	Partially effective; can be obscured by debris, weather English as a second language issue	Proven administrative practice Postings are passive control Reliant on human intervention.	Yes
Access Control (fence and lock)	Physical barrier restricting access to vicinity of transfer lines	Potential interface issues at facility boundaries and where transfer line passes under roads	Fence is passive barrier Fencing commonly used for restricting access	Yes
Chain or Rope	Easily implemented	Easily circumvented depending on inferred meaning of chain/rope	Chain/rope is passive barrier Chain/rope commonly used for restricting access	No Not effective based on ease of circumvention May be considered for use with postings

Table 3.7-4. Initial Evaluation of Preventive Controls

Control Strategy	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Surface Concrete Slab over Pipe Run	Physical barrier to transfer lines Easily implemented, difficult to circumvent depending on design	Allows access to vicinity of transfer lines	Concrete slab is passive barrier No reliance placed on human action Reliance dependent upon inferred purpose of barrier	Yes
Sub-surface Concrete Slab over Pipe Run	Physical barrier and indication of subsurface interferences Commonly employed method	Allows excavation to begin	Concrete slab is passive barrier Reliance dependent upon inferred purpose of barrier	Yes
Jersey Barriers (i.e., elongated concrete blocks) over pipe run	Physical barrier restricting access to vicinity of transfer lines Easily implemented, difficult to circumvent	None	Jersey barrier are passive barrier No reliance placed on human action	Yes
Subsurface Steel Mesh over Pipe Run	Physical indication of subsurface interferences	Allows excavation to begin	Steel mesh is passive versus active barrier Reliance dependent upon inferred purpose of barrier	Yes
Subsurface Cable/tape over Pipe Run	Physical indication of subsurface interferences	Allows excavation to begin	Cable/tape is passive versus active barrier Reliance dependent upon inferred purpose of barrier	Yes
Subsurface Multi-conductor Cable over Pipe Run Interlocked to Alarm	Physical indication of subsurface interferences Notifies operations of excavation activities	Allows excavation to begin Repair of line would necessitate excavation in vicinity of transfer lines False alarms impact reliability	Has both passive and active elements Reliance dependent upon inferred purpose of barrier	Yes

Table 3.7-4. Initial Evaluation of Preventive Controls

Control Strategy	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Operator Surveillance of Pipe Run	Visual determination that no unplanned activities are conducted in vicinity of transfer lines	Effectiveness function of surveillance frequency	Surveillance of transfer routes has been performed at the Hanford Site Surveillance is an active versus passive control and is dependent upon human action	Yes For consideration as a secondary, defense in depth control only
Video Surveillance of Pipe Run	Visual determination that no unplanned activities are conducted in vicinity of transfer lines	Partially effective, function of number of cameras, time of day, and weather conditions	Video surveillance is an active versus passive control and is dependent upon human action	Yes For consideration as a secondary, defense in depth control only

Table 3.7-5. Initial Evaluation of Leak Detection Methods

Control Strategy	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Low Point Leak Detection (i.e., leak drains via gravity to instrumented collection point)	Easily implemented Effective for moderate to large leaks	Time delay between failure and detection as fluid flows to low point Small leaks might go undetected Might not detect guillotine break	Standard practice routinely employed at the Hanford Site and elsewhere Gravity drain is passive aspect of system Signal can be interlocked to automatically shut down the transfer pump	Yes
Leak Detection Cable in Pipe Annulus along Entire Length of Run	Effective, no time delay Can detect small leaks Would likely detect guillotine break Can identify location of failure	More complex system Inert gas may be required to reduce condensation to avoid false negatives Difficulty achieving acceptable reliability	Commercially available, installed at Hanford Site replacement cross-site transfer line Active versus passive system Signal can be interlocked to automatically shut down the transfer pump	Yes
Pressurize Secondary to 1.5X Primary	Effective, continuous, direct Would detect failure of either the primary or secondary Would detect guillotine break	Nitrogen or compressed air system required	Active versus passive system Signal can be interlocked to automatically shut down the transfer pump	Yes
Pressurize Secondary to Low Pressure	Effective, continuous, direct Would detect failure of secondary and would detect failure of primary when not transferring	Nitrogen system required	Active versus passive system Signal can be interlocked to automatically shut down the transfer pump	Yes

Table 3.7-5. Initial Evaluation of Leak Detection Methods

Control Strategy	Advantages	Disadvantages	Compliance with Top-Level Principles	Further Consideration in Control Strategy
Depression monitoring	Effective, continuous, direct Detects failure of secondary line	Does not detect failure of primary pipe Potential for a contaminated airstream	Active versus passive system Signal can be interlocked to automatically shut down the transfer pump	Yes
Receipt Tank Level Monitoring Leak detection monitoring would be secondary function of system Automated rate of change with manual response on alarm	Easily implemented Will be utilized for process control purposes	Not effective at beginning or end of transfer Would not detect small leaks	Active versus passive system	Yes For consideration as a secondary, defense in depth control only
Differential Flow Rate Flow rate meters on each end of transfer line Manual response on alarm condition	Easily implemented	Not effective at beginning or end of transfer Would not detect small leaks	Active versus passive system Proven engineering practice	Yes For consideration as a secondary, defense in depth control only

3.7.3.2.2. Step 2 (Engineering Screen)

The preferred strategy was then developed through an engineering evaluation of the alternatives. This took account of the following considerations to ensure a comprehensive approach in the context of other hazards and the overall design.

- Introduction of secondary hazards
- Impact on safety features provided protect against other hazards
- Impact of other hazards upon the control strategy
- Robustness to other fault conditions and environments (including seismic and other design basis events)
- Passive or active, and if active, automatic or administrative/procedural order of preference
- Robustness of any administrative controls required
- Cost
- Operability
- Maintainability
- Ease of justification (e.g., consistency with proven technology).

Table 3.7-6 presents the evaluation of preventive controls against the above criteria. Table 3.7-7 presents the evaluation of the identified leak detection methods.

Table 3.7-6. Engineering Evaluation of Preventive Controls

Evaluation Criteria	Control Strategy Elements: BNFL Excavation Permit	Postings	Access Control (fenced and locked)	Surface Concrete Slab Over Pipe Run
Introduction of Secondary Hazards	None	None	None	None
Impact on Safety Features Provided to Protect against other Hazards	None	None	Potential interference with Hanford Fire Department response	None
Impact of Hazards upon the Control Strategy	None	None	None	None
Robustness to other Fault Conditions and Environments	None	Vulnerable to extreme weather conditions, i.e., high winds, snow and ice	Potential vulnerability to extreme weather conditions depending on design	Potential impact on seismic qualification of transfer line
Passive or Active	Not applicable	Not applicable	Fence is passive	Passive
Robustness of any Administrative Controls Required	Hanford Site excavation process rigorous and well established	Standard industry practice but relatively easy to disregard Function of disciplined conduct of operations	Requires an access control program	No associated administrative controls
Cost	Not a discriminator, all Hanford Site contractors must have an essentially identical program	Low	Cost is higher than simply providing postings	Cost higher than fencing
Operability	Not applicable	Not applicable	Barrier to required excavation within controlled area	Barrier to required excavation
Maintainability	Not applicable	Must be maintained	Probable requirement to keep vegetation clear	Function of design

Table 3.7-6. Engineering Evaluation of Preventive Controls

	Control Strategy Elements			
Evaluation Criteria	**BNFL Excavation Permit**	**Postings**	**Access Control (fenced and locked)**	**Surface Concrete Slab Over Pipe Run**
Ease of Justification	Existing Hanford Site process	Existing Hanford Site practice	Access control is provided to existing tank farms Access control to transfer lines outside tank farms not standard practice	Not a standard practice at the Hanford Site

Table 3.7-6. Engineering Evaluation of Preventive Controls

	Control Strategy Elements			
Evaluation Criteria	**Sub-Surface Concrete Slab Over Pipe Run**	**Jersey Barriers Over Pipe Run**	**Subsurface Steel Mesh Over Pipe Runs**	**Subsurface Cable/Tape Over Pipe Runs**
Introduction of Secondary Hazards	None	None	None	None
Impact on Safety Features Provided to Protect against other Hazards	None	Potential interference with Hanford Fire Department response	Potential galvanic interaction with transfer lines	Potential galvanic interaction with transfer lines if metal cable used
Impact of Hazards upon the Control Strategy	None	None	None	None
Robustness to other Fault Conditions and Environments	None	None	Deterioration over time due to corrosion	Subject to corrosion if metal cable used; more robust than mesh
Passive or Active	Passive	Passive	Passive	Passive
Robustness of any Administrative Controls Required	No associated administrative controls	No associated administrative controls	No associated administrative controls	No associated administrative controls
Cost	Cost higher than fencing	Less than concrete, higher than fence	Approximately same as fence	Relatively cheap
Operability	Barrier to required excavation	Barrier to required excavation but movable	Barrier to required excavation	Barrier to required excavations
Maintainability	Function of design	Easily maintained, replaceable	None	None
Ease of Justification	Existing Hanford Site process	Existing Hanford Site practice	Not a standard industry practice	Replacement cross-site transfer system uses 6-inch wide tape buried 1 ft below grade over pipe runs

Table 3.7-6. Engineering Evaluation of Preventive Controls

Evaluation Criteria	Control Strategy Elements		
	Subsurface Multi-Conductor Cable	**Operator Surveillance of Transfer Line**	**Video Surveillance of Transfer Line**
Introduction of Secondary Hazards	None	Function of means of performance; potential personal injury, snake/insects	None
Impact on Safety Features Provided to Protect against other Hazards	Potential galvanic interaction with transfer lines	None	None
Impact of Hazards upon the Control Strategy	None	None	None
Robustness to other Fault Conditions and Environments	Subject to corrosion, loss of power	Operator effectiveness sensitive to environmental conditions	Sensitive to climatic conditions (fog); requires lighting, loss of power
Passive or Active	Passive	Active	Active
Robustness of any Administrative Controls Required	Requires operator response to alarm condition	Easily proceduralized	Requires operator monitoring
Cost	Associated I&C costs, operator training costs	Function of frequency; potentially very costly, requires training and communications	High; capital cost, operator surveillance costs
Operability	Loss of power issue	Weather factor	Loss of power issue.
Maintainability	Multi-conductor concept provides redundancy	Not applicable	Potentially demanding
Ease of Justification	No known application	Current Hanford Site practice during transfers through unencased lines	Standard safeguards and security measure

Table 3.7-7. Engineering Evaluation of Leak Detection Methods

Evaluation Criteria	Control Strategy Elements: Low Point Leak Detection	Continuous Leak Detection Cable	Pressurize Secondary to 1.5x Primary	Pressurize Secondary to Low Pressure
Introduction of Secondary Hazards	ALARA issue during maintenance if located within cell	None	Pressurized system, dangerously large quantity of stored energy	Pressurized system - large quantity of stored energy
Impact on Safety Features Provided to Protect against other Hazards	None	None	Requires penetration of secondary line	Requires penetration of secondary line
Impact of Hazards upon the Control Strategy	None	None	None	None
Robustness to other Fault Conditions and Environments	Qualification for radiation fields	Qualification for radiation fields, false positives due to condensation	Pressure will fluctuate due to process temperatures	Pressure will fluctuate due to process temperatures
Passive or Active	Active	Active	Active	Active
Robustness of any Administrative Controls Required	Automated with operator verification	Automated with operator verification	Automated with operator verification	Automated with operator verification
Cost	Moderate to high	Low to moderate	Low	Low
Operability	Not a discriminator	Likely false positive	Issues associated with temperature impacting pressure, requires calibration	Issues associated with temperature impacting pressure - requires calibration
Maintainability	Moderate to high due to probable location within cell	Normally low to moderate May need to abandon in place if fails	Low - easy access	Low - easy access
Ease of Justification	Standard practice	Employed at replacement cross-site transfer line	Difficult to justify given magnitude of secondary hazard	Widely used

Table 3.7-7. Engineering Evaluation of Leak Detection Methods

	Control Strategy Elements		
Evaluation Criteria	**Depression Monitoring**	**Receipt Tank Level Monitoring**	**Differential Flow Rate**
Introduction of Secondary Hazards	Possible contaminated airstream	ALARA issue during maintenance	Potential ALARA issue during maintenance depending on design
Impact on Safety Features Provided to Protect against other Hazards	Requires penetration of secondary line	None	None
Impact of Hazards upon the Control Strategy	None	None	None
Robustness to other Fault Conditions and Environments	May not detect primary line failure Vacuum will fluctuate with temperature	Qualification for radiation fields	Qualification for radiation fields
Passive or Active	Active	Active	Active
Robustness of any Administrative Controls Required	Requires operator response to alarm Standard conduct of operations requirement	Requires operator response to alarm Standard conduct of operations requirement	Requires operator response to alarms Standard conduct of operations requirement.
Cost	Low	Not a discriminator, will be present for process control	Moderate to high, same as low point
Operability		Not a discriminator	Not a discriminator
Maintainability	Low, easy access	Moderate to high based on probable location of within cell	High, Pretreatment monitor located within cell
Ease of Justification	Employed at Sellafield	Tank level monitoring will be provided for routine process control	Comparison algorithm requires use of assumptions to simplify

3.7.3.2.3. Control Strategy Selected

The control strategy selected consists of the following five elements:

- High integrity coaxial transfer line
- BNFL Inc. excavation permit process
- Signposts and postings
- Access control fencing
- Leak detection.

In selecting this strategy, emphasis was placed on preventive over mitigative, passive over active, and automatic over procedural controls.

Prevention. Two preventive control strategy elements, i.e., a high integrity coaxial transfer line and a BNFL Inc. excavation permit process, were specifically selected to support assumptions made in deriving the initiating event frequency of 5 x 10^{-4}/y. A high integrity coaxial transfer line is required to support the assumption that not all mechanical digging equipment is capable of breaching both the primary and secondary pipes. Specifically, the coaxial design provides two schedule 40 pipes as a barrier to release from external events. The high integrity coaxial design also provides two effective barriers to release due to other initiating events such as corrosion, erosion, or overpressurization. A BNFL Inc. excavation permit process equivalent or superior to current Hanford Site practices is required as the current Hanford Site excavation permit process was credited as an assumed initial condition of the unmitigated analysis.

In order to approach the target frequency of 1 x 10^{-6}/y (see Section 3.7.4.1) without undue reliance on human performance, an engineered versus procedural control to excavation is required. Accordingly, operator surveillance of the transfer line, by either video surveillance or physically walking down the line, was not considered for inclusion in the control strategy. Signposts and postings are not an engineered control, however, they were selected for inclusion in the control strategy as they provide a significant level of defense in depth based on the long-standing Hanford Site practice of using signposts to identify the location and routing of underground waste transfer lines.

Of the engineered controls considered, an access control fence was selected based on its relative effectiveness and ease of implementation. Access control fencing was selected over subsurface controls (i.e., steel mesh, cable/tape, multi-conductor cable) as it physically prohibits access to the vicinity of the transfer lines whereas subsurface controls allow excavation activities to begin. Further, the engineering evaluation raised concerns regarding corrosion of the subsurface steel mesh and cables and identified that there are no known applications of those controls for the intended purpose. A subsurface plastic tape placed over the pipe run may be incorporated into the detailed design of the LAW transfer lines for consistency with Hanford Site practices, but is not specifically included in the control strategy.

Access control fencing was selected instead of a concrete slab poured on the surface of the ground along the transfer route based on two considerations. First, portions of the transfer line are bermed and would require concrete on the three faces of the berm. The rigidity of concrete could conceivably impact the seismic qualification of the line. Second, concrete slabs are not employed for the intended purpose at the Hanford Site.

Access control fencing was selected instead of Jersey barriers based on two considerations. First, it is judged that excavation equipment operators would be more likely to circumvent the Jersey barriers by using their equipment to slide the barriers out of the way than they would be to take down a portion of the fence. Second, access control fencing is commonly employed at the Hanford Site to restrict access to areas for either hazard control or safeguards and security reasons. Accordingly, fencing constitutes a recognized and respected barrier.

Although access control fencing represents a passive, engineered barrier, there is an associated administrative element. An access control program is required to evaluate and approve requested entries into the controlled area defined by the fence.

Mitigation. A leak detection system interlocked with the transfer pumps to automatically stop the transfer was selected as an element of the control strategy to provide a mitigative, defense in depth feature. The engineering screen did not result in the selection of a preferred leak detection strategy. A more rigorous trade study of will be performed during detailed design to further evaluate, either singularly or in combination, the following methods:

- Low point leak detection
- Continuous leak detection cable
- Low-pressure secondary
- Depression monitoring.

The trade study will also include research to identify leak detection methods not previously considered or evaluated (e.g., monitoring airflow through the secondary pipe to detect radioactivity). Selection of the preferred leak detection method will consider all credible failure modes.

Receipt tank level monitoring and differential flow rate were not selected for further consideration at this time based on their ineffectiveness at the beginning and end of transfers and current uncertainty regarding the size of leak that could be detected. Receipt tank level monitoring will be performed for process control purposes and will provide a defense in depth function.

Pressurization of the secondary pipe to 1.5 times the primary pipe pressure was not selected for further consideration at this time based on the magnitude of the secondary hazard introduced by pressurizing 3,300 ft (1,000 m) of pipe to pressures on the order of 210 psig. This represents a significant quantity of stored energy and failure of the secondary pipe could conceivably result in severe injury to personnel depending on the location and circumstances of the failure. It is recognized that high pressure piping systems can be safely designed and operated and that such systems are routinely employed in industry. However, viable alternate leak detection methods that do not introduce secondary hazards are available.

3.7.3.3. Structures, Systems, and Components That Implement the Control Strategy

Structures, systems, and components (SSCs) that are relied upon to implement the control strategy include the following:

- High integrity coaxial transfer line piping
- Signposts and postings
- Access control fencing
- Leak detection system.

Electrical power is not relied upon to implement the control strategy as a performance requirement of the leak detection system is to stop the transfer on loss of power (see Section 3.7.4.2).

3.7.4. Safety Standards and Requirements

3.7.4.1. Reliability Targets

The target frequency for the overall control strategy is 1×10^{-6}/y based on SL-1 consequences to the equipment operator and co-located worker. To achieve this target frequency for the equipment operator, the combination of signposts and postings that identify the transfer line route and the access control fencing must support a human error probability of 2.0×10^{-3}. This value is derived by dividing the target frequency by the initiating event frequency, i.e., $(1 \times 10^{-6}/y)/(5 \times 10^{-4}/y) = 2.0 \times 10^{-3}$. The mitigative control strategy of leak detection and automatic pump shutdown does not significantly reduce the consequences to the excavation equipment operator. As will be shown in Section 3.7.5.3, the volume of waste released by the draining of the transfer line following pump shutdown is sufficient to result in SL-1 consequences to the equipment operator.

The target frequency for the co-located worker is 1×10^{-6}/y based on SL-1 consequences. The preventive controls of signposts and postings and access control fencing discussed above for the equipment operator also protect the co-located worker. In addition, the mitigative control strategy of leak detection reduces the consequences to the co-located worker by limiting the quantity of LAW leaked. Leak detection thereby serves an important defense in depth function. To provide an additional margin of safety, the leak detection system design should support a failure rate on the order of 1×10^{-2}/demand. Note that WAC-173-303 requires the leak detection system to be capable of detecting a leak with a probability of detection of 0.95.

The target frequency for the public is 1×10^{-2}/y based on SL-3 consequences. As the initiating event frequency is less than the target frequency, only those elements of the control strategy that support assumptions made in deriving the initiating event frequency (i.e., high integrity coaxial pipe and BNFL Inc. excavation permit process) are specifically required for protection of the public. The remaining control strategy elements provide defense in depth.

3.7.4.2. Performance Requirements

Prior to defining SSC-specific performance requirements, overall control strategy performance requirements for natural phenomena hazards and aircraft strike must be developed. As stated in *Safety Requirements Document* (BNFL Inc. 1998d), SSCs designated as important to safety shall be designed to withstand the effects of natural phenomenon hazards events without loss of capability to perform their specified safety functions. As identified in Section 3.7.2.6.1, design basis natural phenomena with the potential to cause failure of the both the primary and secondary pipes include seismic, high wind, wind-generated missiles, and precipitation. Based on SL-1 consequences to the co-located worker, the applicable design loads are taken from Table 4-1 of BNFL Inc. (1998d). In summary, the design loads are:

- Seismic event = 0.24 g horizontal, 0.16 g vertical acceleration
- Straight wind = 111 mi/h (49.6 m/s), 3-second gust

- Wind missile = 2 x 4 timber plank at 50 mi/h (22 m/s)
- Precipitation = 3.9 in. (10 cm) for 6-h precipitation.

Preventive control strategy elements selected for the specific event sequence analyzed in Section 3.7.2.2 do not prevent LAW transfer line failures from design basis natural phenomena. The leak detection system would mitigate the consequences of a transfer line failure by limiting the volume of LAW leaked, given it can be demonstrated that the transfer pump would shut off given plausible failures initiated by the natural phenomena event.

A seismic event, in particular, could fail both the primary and secondary pipes and result in random leak detection instrumentation and control system failures such that shut down of the transfer pump can not be easily demonstrated.

High wind and precipitation could potentially erode portions of the berm and weaken the foundation of the transfer line, which in turn could lead to subsequent failure of both the primary and secondary pipe. High wind and precipitation are not likely to cause the simultaneous failure of the leak detection system. Although high wind and precipitation could result in a simultaneous loss of power, a performance requirement of the leak detection system is that it shut down the pump on loss of power (see Section 3.7.4.2.5). Accordingly, leak detection and pump shutoff is a viable, mitigative control for high wind and precipitation, contingent upon final leak detection design.

A wind-generated missile could conceivably penetrate the transfer line berm and fail both the primary and secondary pipe. Similar to the high wind and precipitation events, a wind-generated missile is not likely to cause the simultaneous failure of the leak detection system. Accordingly, leak detection and pump shutoff is a viable control for wind-generated missiles, contingent upon final leak detection design.

Although leak detection is a viable mitigative control strategy for some natural phenomenon events, preventive controls are preferable. Therefore, the LAW transfer lines (and the associated berm as required) will be designed to withstand the natural phenomenon design loads.

As identified in Section 3.7.2.6.2, the transfer lines are vulnerable to aircraft crash. The frequency of an aircraft crash into the TWRS-P facility is estimated to be 4.5×10^{-6}/y (BNFL Inc. 1997). This frequency approaches the target frequency for an SL-1 event. The probability that a LAW transfer is in progress at the time of the event can be calculated based on the number of hours per year that transfers are conducted. Assuming the highest transfer rate of once every 3 days (based on 3M Na, 60 t/d throughput) and a transfer duration of 7 hours (based on 140 gpm (32 m^3/h) and a LAW evaporator feed vessel maximum operating volume of 60,000 US gal (225 m^3), the probability is equal to ([365/3] x 7)/(365 x 24) = 1×10^{-1}. Combining the event frequency with the probability of a concurrent transfer yields a frequency of $(4.5 \times 10^{-6}/y) \times (1 \times 10^{-1}) = 4.5 \times 10^{-7}/y$. This is below the target frequency of 1×10^{-6}/y such that aircraft crash need not be considered further.

3.7.4.2.1. Coaxial Transfer Piping

The coaxial piping must provide primary and secondary containment of the LAW. Secondary containment is required by WAC-173-303. WAC-173-303 further requires that the piping be supported and protected against physical damage, and excessive stress due to settlement, vibration, expansion, or contraction. The LAW transfer line materials of construction must comply with WAC-173-303 requirements for compatibility with the process fluid, and be of sufficient strength and thickness to prevent failure caused by design basis pressure gradients, climatic conditions, and dead and live loads. The secondary pipe must be protected from external corrosion. **Design Assumption**.

The coaxial piping must provide containment given a design basis seismic event. This may be accomplished by seismically qualifying the primary pipe, the secondary pipe, or both. If only one pipe is qualified, failure of the non-qualified pipe must not result in failure of the qualified pipe.

The coaxial pipe must provide containment given design basis wind, wind-generated missile, and precipitation events. This performance requirement potentially impacts the design of both the coaxial pipe and the berm that covers the coaxial pipe for a significant portion of the route.

The secondary containment pipe is a component of the leak detection system (see Section 3.7.4.2.5). Additional performance requirements for the secondary pipe will be determined following selection of a preferred leak detection method. As an example, if gravity drain low point leak detection is selected, then the secondary containment pipe must direct flow of leaked waste to the point of detection.

3.7.4.2.2. BNFL Inc. Excavation Permit Process

The BNFL Inc. excavation permit process must prevent inadvertent excavations in the vicinity of the LAW transfer lines. In addition, the permit process must ensure that excavations intentionally conducted in the vicinity of the transfer lines are controlled such that the integrity of the lines is not threatened. Further, the permit process must ensure that emergency response actions are identified in the event an underground transfer line is breached.

3.7.4.2.3. Signposts and Postings

The signposts and postings must identify the transfer line route and alert individuals to the presence of an underground radioactive waste transfer line. The postings must employ commonly used symbols and language. The posts and postings must be of robust construction such that they are not easily damaged, and must be designed to withstand and remain legible given expected weather conditions.

3.7.4.2.4. Access Control Fencing

Access control fencing must prevent unauthorized access to the vicinity of the transfer lines. The distance between the transfer lines and fencing must be sufficient to preclude damage to the transfer lines from excavation activities outside the fence. The fencing must be posted to alert individuals that unauthorized access is prohibited.

The fence must be of reasonably robust construction (e.g., chain-link) such that it is not easily damaged by human or animal activity. The fencing and the postings must be designed to withstand expected weather conditions.

Entry points to the controlled area defined by the fencing must be sized to prevent access by mechanical digging equipment. An access control program must ensure that access is authorized only after a proposed activity has been evaluated for potential hazards. The evaluation must include a review of the proposed activity by suitably qualified operations personnel. The access control program must also address control at interface points. Application of the access control fencing strategy to locations where the transfer lines pass under roads requires further evaluation. **Open Issue.** Excavation permit processes and the access control program provide administrative means of controlling road maintenance activities. Consideration will be given to the use of subsurface controls (e.g., concrete slab or tape) at the specific locations where the transfer lines pass under roads.

3.7.4.2.5. Leak Detection

Leak detection is required by WAC-173-303. The leak detection system must detect the leakage of waste from the primary pipe to the secondary containment. Upon detection of the leak, the system must automatically stop the transfer. The leak detection system must be able to detect a guillotine break. If the system cannot detect a guillotine break, then a secondary means of detecting such a leak is required (e.g., LAW evaporator feed vessel monitoring).

The design shall be "fail safe" such that the transfer pump will automatically shut down on loss of power to the leak detection system.

3.7.4.3. Administrative Measures

The principal administrative controls required to implement the control strategy is the development and administration of an excavation permit process and access control program. Additional administrative measures required to assure selected control strategy are as follows:

<u>Normal operations</u>

Normal operations will be conducted in accordance with approved operational safety requirements and in strict accordance with administrative and procedural control. Operators will be trained and assessed on the conduct of normal operations. Operational procedures, routine schedules and records will augment training.

Operator procedures will be developed for the routine operation of waste transfer from tank 241-AP-106. The operator instruction provides a systematic approach to complete all the necessary activities of the task. The operator instruction will detail roles and responsibilities, levels of authority, hazards and precautions and operational decision points.

The key steps associated with the feed transfer from tank 241-AP-106 are:

- Confirmation of feed specification
- Establishing levels within the feed and receipt tanks (confirmation of ullage availability)
- Monitoring of feed and receipt and confirmation of expected rate of arising
- Periodic leak detector operability testing.

The operational decision point of when to start operations, is dependent on satisfactory receipt of feed specification.

A routine operating schedule will be established for checking the leak detector operability prior to transfer operations. A record will be maintained demonstrating this operation has been completed. Routine activities will be assigned to a responsible person.

Arrangements for the examination, inspection, maintenance and testing of all Important-to-Safety equipment will be managed through a plant maintenance schedule. All maintenance activities will be carried out using appropriate maintenance instructions. This will include the maintenance of signposts and postings, fencing and physical barriers.

Operator response to abnormal conditions

Operators will be trained to identify, diagnose and respond to abnormal operating conditions. Plant information will be relayed to the operator in such a manner to aid the operator in performing this duty. Typically any deviation of the process from its normal operating condition will generate an alarm appropriate to its importance. The alarm will annunciate at the operator workstation or locally within the facility. Details to be included in the operational procedures are as follows:

- Actions the operator must perform to minimize the impact of the abnormality
- Potential initiators
- Follow up actions required, when plant conditions have been stabilized.

There will be training and operational procedures to ensure the correct responses are carried out by operators in abnormal conditions. Abnormal conditions are as follows:

- High level inside the receipt vessel. The purpose is to minimize the challenges made to the vessel vent overflow collection system.

- Leak detection alarm.

Emergency Response

Facility operators and external contractors in the employment of the TWRS-P facility will be trained in what action is to be taken on a suspect breach of the LAW transfer line. The emergency response primary action will be to evacuate the area, and to minimize the impact of the leak by initiating the emergency response structure.

3.7.4.4. Administrative Standards

Operation of the TWRS facilities shall be conducted in accordance with proven practices from BNFL operations in the UK and the US. Arrangements will be in place to maintain and demonstrate compliance with all Safety Criterion detailed within the authorization basis.

Administrative arrangements will provide the framework for how facility operations will be conducted for all modes of operation, be that normal, maintenance or emergency preparedness.

The conduct of operation guidelines will be generated by the tailored application of appropriate sections of the following standards:

IAEA 50-C-0: Code on the Safety of Nuclear Power Plants Operation
DOE Order 5480.19 “Conduct of Operations Requirements for DOE Facilities”.
DOE Order 4330.4B “Guidelines for the Conduct of Maintenance at DOE Nuclear Facilities”.
“Appropriate standards” from the Institute for Nuclear Power Operations.

This framework of conduct will be implemented through:

- Management and organization structure.
- Documents, records and certification, including response to abnormal operating conditions, key compliance recording and archiving.
- Structured training programs for all personnel, tailored to their roles and responsibilities.
- Emergency preparedness implemented by having an emergency response structure, training, exercises and procedures.
- Incident reporting arrangements.
- Safety documentation hierarchy, with appropriate flow down of information into operational documentation. All safety implications will be clearly identifiable within the operational procedures.
- Quality assurance.
- Arrangements for the examination, inspection, maintenance and testing of all Important-to-Safety equipment.
- Labeling of Important-to-Safety equipment clearly on the facility.

3.7.4.5. Design Standards

The coaxial transfer line will be designed in accordance with the following standards:

- ASME B31.3, *Process Piping*, *Category M Fluid Services* (ASME 1996)
- DOE Standard 1020-94, *Natural Phenomenon Hazards Design and Evaluation Guideline for Department of Energy Facilities* (DOE 1994b)
- ASME 78-PVP-82, *Flexibility Analysis of Buried Pipe* (ASME 1978)
- *Seismic Response of Buried Pipes and Structural Components* (ASCE 1983).

Additional design standards may apply and are being investigated, e.g., *Seismic Design and Evaluation Guidelines for the Department of Energy High-Level Waste Storage Tanks and Appurtenances* (BNL 1993) and *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* (NACE 1992). **Open Issue**.

Design standards for the leak detection instrumentation and control system and associated hardware will be developed on a component-by-component basis following selection of a preferred leak detection method. Instrumentation and control design standards will be derived based on BNFL Inc. and BNI design experience. **Open Issue**.

There are no known national consensus codes and standards for the design of signposts and access control fencing. Standards will be developed during detailed design.

3.7.4.6. Standards Not in the Safety Requirements Document

Of the four design standards specifically identified in Section 3.7.4.4, the following two are not identified in BNFL Inc. (1998d):

- ASME 78-PVP-82, *Flexibility Analysis of Buried Pipe* (ASME 1978)
- *Seismic Response of Buried Pipes an Structural Components* (ASCE 1983).

3.7.5. Control Strategy Assessment

3.7.5.1. Performance Against Common Cause and Common Mode Effects

No common cause or common mode effects other than natural phenomenon and man made effects have been identified for failure of the LAW transfer line. The control strategy specifically requires that the coaxial pipe be designed to maintain containment given the occurrence of design basis natural phenomenon events. This will be achieved through the selection, and as required, the development of standards for the design and construction of the coaxial pipe and associated berm.

3.7.5.2. Comparison with Top Level Principles

3.7.5.2.1. Defense in Depth (DOE/RL-96-0006)

Defense in depth is one of the general radiological and nuclear safety principles in DOE/RL-96-0006. SRD Volume II, Appendix B, contains the BNFL Inc. *Implementing Standard for Defense in Depth*. This Implementing Standard governs application of the defense in depth principle for the TWRS-P project.

To satisfy the application of defense in depth, the Implementing Standard requires that the elements of the control strategy must ensure "…that no one level of protection is completely relied upon to ensure safe operation. This safety strategy provides multiple levels of protection to prevent or mitigate an unintended release of radioactive material to the environment."

DOE/RL-96-0006 formulates the defense in depth principle in terms of the following six sub-principles:

- Defense in depth
- Prevention
- Control
- Mitigation
- Automatic systems
- Human aspects.

The implementing standard governing application of the defense in depth principle for the TWRS-P project addresses each of the six sub-principles. The following paragraphs describe application of the Implementing Standard for defense in depth to the LAW pipe break control strategy.

1. Defense in Depth (4.1.1.1). DOE/RL-96-0006, Section 4.1.1.1, requires the following:

   "To compensate for potential human and mechanical failures, a defense-in-depth strategy should be applied to the facility commensurate with the hazards such that assured safety is vested in multiple, independent safety provisions, not one of which is to be relied upon excessively to protect the public, the workers, or the environment. This strategy should be applied to the design and operation of the facility."

   Section 3.0 of the Implementing Standard specifically addresses this aspect of defense in depth. For SL-1 events, Section 3.0 requires:

   - Two or more independent physical barriers to confine the radioactive material
   - Application of the single failure criterion
   - A target frequency of < 1 x 10^{-6}/y for the SL-1 consequences.

   The coaxial pipe design provides two physical barriers against the release of radioactivity to the environment. However, this arrangement is vulnerable to common cause failure by excavation equipment. Therefore, the control strategy provides a third, independent physical barrier in the form of access control fencing.

   The single failure criterion in the Implementing Standard requires that, given an initiating event, the control strategy must be able to tolerate failure of any single active component in the short term. The control strategy must also be able to tolerate a single passive failure in the long term. The single passive failure is to be a mechanistic failure (e.g., pump seal leakage); the single passive failure is not a deterministic failure (e.g., pipe break). Section 2.1.2 of the Implementing Standard requires application of the single failure criterion to fluid, electrical, and instrumentation and control systems. The control strategy for LAW pipe break incorporates a leak detection system. This system satisfies the single failure criterion in the Implementing Standard.

   The analysis in Section 3.7.5.6 indicates that the control strategy reduces the frequency of SL-1 level consequences for the LAW pipe break to less than 1 x 10^{-6}/y. This satisfies the target frequency in the Implementing Standard.

   The analyses in Sections 3.7.5.3 and 3.7.5.4 show that the mitigating elements of the control strategy reduce the consequences for the LAW pipe break to SL-2 levels for the co-located worker and SL-4 consequences for the public, but not below SL-1 for the excavation equipment operator. The frequency of this event is < 1 x 10^{-6}/y, which meet the Implementing Standard frequency for SL-1 events. This is considered acceptable because the dose to the equipment operator is based on very conservative assumptions and, at 28 rem, is just above the SL-1 threshold of 25 rem.

2. Prevention (4.1.1.2). The emphasis in the selected control strategy is prevention of the release by preventing access to the transfer line by excavation equipment. Access and work control, including the permit process, would reduce the likelihood of excavation activities in the area while waste is being transferred. Signposts and postings reduce the likelihood that the operator would proceed with excavation. Access control fencing provides a physical barrier that the equipment operator must overcome with difficulty if he remains intent on proceeding.

3. Control (4.1.1.3). The primary and secondary transfer lines will be designed to handle conditions expected during normal operations and expected off-normal occurrences. The chemistry of the waste streams, pressure, and temperature will be controlled within limits that provide adequate margin to the capability of the lines to continue their safety function of containing waste for the facility lifetime.

   There are no operating parameters that affect or degrade the safety function of the signposts and postings and access control fencing.

4. Mitigation (4.1.1.4). The conservatively designed confinement system for the LAW transfer line is the secondary pipe, designed to confine liquor leaking from the primary line and drain it toward the pretreatment facility where it is collected and remains within physical barriers.

5. Automatic Systems (4.1.1.5). The selected control strategy provides for a system to detect a leak and automatically stop the transfer. In the case of a leak in the primary pipe only, a low-point leak detection system interlocked to automatic shutdown of the transfer pump limits the quantity of waste that would drain into the facility and potentially spread to the environment. However, in the case of a break in both lines, the liquor could leak to the ground through the break in the secondary line rather than drain to low-point leak detection system. Therefore, to minimize the release to the environment, the leak detection strategy selected must include provision for automatic pump shutdown in case of a leak that might not drain to the low point.

6. Human Aspects (4.1.1.6). The LAW transfer operation will be designed taking human factors engineering into account. In devising the preventive barriers to the excavation event (i.e., work control, signposts and postings, access control fencing) human factors engineering must be carefully considered in order to provide the required reliability for these controls. Since the Severity Level is SL-1, the control strategy, per Section 2.6.2 of the Implementing Standard, must be reviewed against the human factors engineering criteria in IEEE Std. 1023-1988 6.11, as tailored by the Implementing Standard.

3.7.5.2.2. Operating Experience and Safety Research (4.1.2.4)

Buried pipelines for transfer of both gases and liquids are commonly employed by a number of industries. Research into the success and reliability of programs and controls devised to prevent inadvertent excavation of buried lines can provide information for designing the administrative controls required to prevent the accident. Information about the requirements for excavation permits currently operable on the Hanford Site was researched for this exercise. Additionally, research into the effectiveness and reliability of various leak detection methods will be conducted.

3.7.5.2.3. Proven Engineering Practices (4.2.2.1)

The control strategy elements, pipe-in-pipe construction, work control, signposts and postings, access control fencing, and leak detection interlocked to automatic pump shutdown, are all practices typically used for waste transfers. Methods selected for implementing the control strategies will use proven engineering practices, including the over 40 years of Hanford operating experience.

3.7.5.2.4. Common Mode/Common Cause Failures (4.2.2.2)

The initiator of the loss of confinement event examined in this example, damage to the transfer line by mechanical digging, provides a common cause of failure of both the primary and secondary confinement systems. Therefore, the control strategy provides multiple independent barriers (work control and physical barriers) to prevent this event. The work control procedures and the physical barriers will be such that they cannot both be overcome by any common mechanism, notably, human error.

3.7.5.2.5. Safety System Design and Qualification (4.2.2.3)

The primary pipe will be stainless steel, rated for the expected chemical composition of the waste stream. Compatibility with the soil, and with external environmental conditions, will be considered in selecting the material of construction for the secondary pipe. The system will be electrically isolated for corrosion protection. The effect of aging on the pipeline materials will be considered in the design.

The signposts and postings provided to alert individuals of the presence of a buried transfer line must be designed to remain in place and be capable of being maintained to be clearly legible through expected weather conditions including wind, dust storms, snow and ice. The access control fencing and associated postings must be designed to physically prevent access to the transfer line through all expected environmental conditions.

The leak detection system(s) and associated electrical interlock will be designed to operate in the chemical and physical environment in which they are located. These systems will be verified as operational prior to transfers.

3.7.5.2.6. Radiation Protection Features (4.2.3.2)

The primary radiation protection feature in the design of the transfer line is the soil covering (buried line or berm) providing shielding when waste is being transferred. The BNFL Inc. work control process will link the excavation permit process and the process for establishing appropriate radiological controls during the performance of the work. These work processes will ensure that worker exposures are ALARA. The control strategy has been subjected to an ALARA design review which concluded that the selected strategy has no adverse ALARA impact (Pisarcik 1999).

3.7.5.2.7. Deactivation, Decontamination and Decommissioning Design (4.2.3.3)

The transfer line will be flushed with filtered raw water after each transfer of radioactive waste. This is not an element of the control strategy for preventing or mitigating the consequences of an excavation accident. However, flushing will facilitate decommissioning by preventing radionuclide buildup in the lines over the years of their use. This will reduce radiation exposures to workers and the public during and following deactivation and decommissioning, and minimize the quantity of radioactive waste generated during decommissioning.

None of the elements of the selected control strategy are expected to either facilitate or hinder effective deactivation, decontamination and decommissioning activities.

3.7.5.2.8. Emergency Preparedness – Support Facilities (4.2.4)

Providing automatic pump shutdown on loss of power to the leak detection system would contribute to placing the facility in a safe state following an accident that causes the normal control areas to become uninhabitable, if that accident could involve localized loss of power.

3.7.5.2.9. Inherent/Passive Safety Characteristics (4.2.5)

The outer pipe that provides secondary confinement of the radioactive liquor in the event of a leak in the primary line is a passive element of the control strategy and also serves as a passive element to prevent excavation equipment from impacting the transfer line.

3.7.5.2.10. Human Error (4.2.6.1)

Because the accident is initiated by human error, the focus of selecting preventive aspects of the control strategy was prohibiting the excavation operator from making a wrong decision with respect to where he will dig. The work control processes, including requirements for excavation permits, sign posting of the area, and access control fencing all inhibit a wrong decision by the operator relative to where to dig.

3.7.5.2.11. Instrumentation and Control Design (4.2.6.2)

Instrumentation that will be provided for operators to monitor the transfer system will include leak detection signal (depending on the type of leak detection system selected), waste temperature, line pressure, flow rate, and receipt tank liquid level. The adequacy of the instrumentation and control capability of the transfer system to allow operators to diagnose facility conditions and place the facility in a safe state, and the need for protection of the operator in the performance of the required functions will be evaluated as design progresses.

3.7.5.2.12. Safety Status (4.2.6.3)

Parameters that are needed to alert the operator of a leak in the transfer line during waste transfer and to assist him in identifying and diagnosing the operation of the pump shutoff interlock will be selected for monitoring. The displays for the parameters selected for monitoring will be clear and unambiguous.

3.7.5.2.13. Reliability (4.2.7.1)

Reliability targets assigned to the important to safety SSCs, as discussed in Section 3.7.4.1, include the following:

Combined signposts and across control fencing	Human error probability of 2×10^{-3}
Leak detection and pump shutdown system	Failure rate of 1.0×10^{-2} per demand

3.7.5.2.14. Availability, Maintainability, Inspectability (4.2.7.2)

The primary and secondary pipes, the signposts, the physical barrier to prevent digging, and the leak detection system(s) with interlocks to the pumps will be designed such that inspection, testing and maintenance to verify their continued acceptability for service throughout their operating lives can be performed.

3.7.5.2.15. Pre-Operational Testing (4.2.8)

Hydrostatic testing of the primary and secondary pipes will be performed after installation and prior to first use. A pre-operational testing program will be established and followed to demonstrate that the transfer system functions as intended. During pre-operational testing, procedures for waste transfer will be validated, detailed diagnostic data will be collected and initial operating parameters will be recorded, and the as-built operating characteristics of the system will be documented.

3.7.5.3. Mitigated Consequences

The radiological consequences and associated severity level of the mitigated event sequence are:

- Equipment operator 28 rem, SL-1
- Co-located worker 9.5 rem, SL-2
- Public 0.012 rem, SL-4

The mitigated event sequence takes credit for the leak detection system detecting the leak and automatically stopping the transfer. The quantity of LAW that drains from the failed line after the transfer is stopped is a function of the location of the failure. If the leak were to occur near the pretreatment facility, one line volume, or 1,100 US gal (4.2 m^3) could be leaked. The consequence calculations assume that one line volume drains from the failed pipe and forms a pool approximately 16 ft (5 m) in radius. It is assumed that the pool is quickly absorbed into the soil such that consequences to the co-located worker and the public are based on the resuspension of contaminated soil only. Details of the consequence calculations are documented in Kummerer (1999a) and Woodruffe (1999).

Because it is assumed that the equipment operator does not recognize the hazard and self-evacuate, the consequences remain SL-1. The dose is reduced approximately 18% from the unmitigated scenario analyzed in Section 3.7.2.2 due to smaller pool size (i.e., from 34 to 28 rem). This emphasizes the importance of training and the inclusion of emergency response provisions in the excavation permit process.

Relative to the unmitigated consequences, the dose to the co-located worker at decreases from 130 rem to 9.5 rem, and the corresponding severity level is reduced from SL-1 to SL-2. The dose the public decreases from 0.53 to 0.012 rem, and the corresponding severity level is reduced from SL-3 to SL-4.

3.7.5.4. Frequency of Mitigated Event

The mitigated event credits the leak detection system but assumes failure of the preventive control strategy elements of signposts and postings and access control fencing. The apportioned target frequency for these preventive measures is 2×10^{-3}.

The first barrier the excavation equipment operator would be confronted with is the access control fencing. Given the performance requirement that access control points be size to preclude mechanical digging equipment, the probability that the operator would intentionally circumvent (i.e., remove or break through) the fencing is estimated to be 1×10^{-3}. This estimate is judged to be conservative as such an act is beyond a simple error of omission or commission, and borders on sabotage. Given such an act, no additional reduction in frequency for the signposts and postings can be reasoned. Combining the initiating event frequency of 5 x 10^{-4}/y with a probability of 1 x 10^{-3} yields an event frequency of (5 x 10^{-4}/y) x (1 x 10^{-3}) = 5 x 10^{-7}/y, which is less than event target frequency of 1 x 10^{-6}/y.

3.7.5.5. Consequences with Failure of the Control Strategy (Including Mitigation)

Given the initiating event and assuming failure of all control strategy elements (i.e., both preventive and mitigative), the consequences are the same as determined in Section 3.7.2.3.

3.7.5.6. Frequency of Control Strategy Failure

Failure of the overall control strategy includes failure of both preventive and mitigative measures. As discussed in Section 3.7.5.3, the mitigative measure of leak detection provides little risk reduction to the excavation equipment operator. Accordingly, credit is given only to the access control fencing. The frequency is therefore 5 x 10^{-7}/y, as calculated in Section 3.7.5.4, which is less than the target frequency of 1 x 10^{-6}/y.

The following tables summarize the mitigated event and control strategy failure consequences and frequencies.

Summary of Results (Mitigated)[a]

Population	Dose (rem)	Severity Level	Frequency (y^{-1})
Equipment Operator	28	SL-1	<1 x 10^{-6}
Co-located Worker	9.5	SL-2	<1 x 10^{-6}
Public	0.012	SL-4	<1 x 10^{-6}

Notes:
[a] Credits success of the leak detection system to limit the release.

Summary of Results With Failure of Control Strategy[a]

Population	Dose (rem)	Severity Level	Frequency(y^{-1})
Equipment Operator	34	SL-1	<1 x 10^{-6}
Co-located Worker	130	SL-1	<1 x 10^{-6}
Public	0.53	SL-3	<1 x 10^{-6}

Notes:
[a] Does not include credit for leak detection system

3.7.6. Conclusions and Open Issues

3.7.6.1. Conclusions

A guillotine break of a LAW transfer line due to inadvertent excavation activities has been analyzed. The break is assumed to result in a large pool of LAW on the surface of the ground. A control strategy has been developed that provides an acceptable level of protection for the equipment operator, the co-located worker, and the public. The control strategy is summarized in Table 3.7-8.

As discussed in item #3 of Section 3.7.6.2 below, HLW transfer line accidents will be analyzed during design development. However, the event sequence analyzed in Section 3.7.2.2 can be used to estimate the consequences of a guillotine break as HLW will be transferred at the same nominal flow rate as LAW and will be received in vessels of identical size as the LAW evaporator feed vessels. The frequency of HLW transfers varies as a function of solids concentration, which will range from 10 to 200 g/L. At 10 g/L it will take 7 days to process one batch. At 200 g/L, it will take 142 days (Washer 1999). Over the life of the facility, HLW transfers will occur at a lower frequency than LAW transfers. At the 200 g/L maximum value, the HLW unit liter dose is 2.02×10^7 rem/L (Kummerer 1999b). This is a factor of 2 higher than the unit liter dose of 1.02×10^7 rem/L for 10M Na LAW (Kummerer 1999a). Holding all other parameters (e.g., pool size, release fraction) constant, the consequences to the co-located worker and public due to the guillotine break of a HLW transfer line would be, at worst, approximately twice those reported for LAW. The dose to the equipment operator would be approximately 4 times greater based on the ratio of the ^{137}Cs concentrations, i.e., 4.73 Ci/L for HLW and 1.26 Ci/L for LAW (Kummerer 1999a, 1999b). These increases in consequence do not change the equipment operator or co-located worker severity levels. For the public, the unmitigated event severity level increases from SL-3 to the lower bound of SL-2, but remains SL-4 for the mitigated event. Therefore, although HLW has not been explicitly analyzed, it is anticipated that the control strategy developed for LAW will serve to adequately protect the equipment operator, co-located worker, and public from excavation accidents involving HLW transfer lines.

3.7.6.2. Open Items

Open issues that require resolution during design development include:

1. Leak Detection System Design. A leak detection system is a requirement of WAC-173-303 and is an implementing SSC of the control strategy. Several candidate leak detection methods were evaluated (see Table 3.7-5 and **Error! Reference source not found.**7). Additional research of the identified methods, as well as continued research to identify alternate methods, will be performed as a part of design development.

2. Initiating Event. The initiating event analyzed in Section 3.7.2.2 is an inadvertent excavation activity. Other initiating events include corrosion, erosion, water hammer, dead head pressure, extreme temperature, manufacturing defects, construction defects, and subsidence. Credible initiating events will be evaluated during design development to ensure the identification of a comprehensive set of design safety features.

3. Spray and Pool Scenarios for HLW and LAW. The specific event sequence analyzed in Section 3.7.2.2 is a guillotine break of a LAW transfer line that results in a pool. An excavation accident could conceivably result in a line break that results in a spray of waste. Additionally, the

HLW transfer lines are adjacent to the LAW transfer lines and are a subject to the same initiating events. A spray release of HLW would have the greatest radiological consequences. In addition to failure of the underground portions of the transfer lines, piping or valve failures or valve misalignments in the new pump pit could result in either spray or pool releases. A comprehensive hazard and accident analysis of the HLW and LAW transfer systems will be performed during design development.

4. Toxicological Consequences. A method for calculating the toxicological consequences associated with pool and spray releases of HLW and LAW will be developed. Consideration will be given to the applicability of the sum-of-fraction methodology used in HNF (1997b).
5. Skyshine Calculations. Radiological consequences presented in Section 3.7.2.3 do not include the contribution from skyshine. Calculations documented in *Calculation Note for Subsurface Leak Resulting in a Pool, TWRS FSAR Accident Analysis* (WHC 1996) show that skyshine can account for 7% of the total dose. Future analyses will include a skyshine component.

6. Additional Design Standards for Underground Pipe. ASME B31.3, *Process Piping*, is the consensus standard for the LAW transfer line primary and secondary containment piping. Additional design standards will be identified and reviewed for applicability during design development. Advantage will be taken of engineering studies performed-to-date for existing Hanford Site systems, e.g., *Requirements Analysis Study for Transfer Piping Project Development Specification* (HNF 1998).

7. Leak Detection System Design Standards. As stated in Item #1 above, the method of leak detection has not yet been selected. Following selection, design standards will be applied commensurate with the system reliability target.

8. Application of the Access Control Fencing Strategy. Application of the access control fencing strategy to locations where the transfer lines pass under roads requires further evaluation. Consideration will be given to the use of subsurface controls (e.g., concrete slab or tape) at the specific locations where the transfer lines pass under roads.

In addition to the open issues listed above, various design and operational assumptions are highlighted in the report. Their continuous validity will be monitored through design development.

Table 3.7-8. Control Strategy Summary

Hazard Description: Guillotine Break of a Low Activity Waste Transfer Line				**Initiator:** Inadvertent Excavation Activity	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Coaxial transfer line	Primary pipe	Primary containment barrier	Verification that DOE transfers to tank 214-AP-106 comply with contract specifications Qualified for natural phenomena hazards such that containment is provided by either the primary or secondary pipe	Constructed of 3-in. schedule 40 stainless steel	
	Secondary pipe	Secondary containment barrier To route (as necessary) waste leaked from the primary pipe such that it can be detected	External corrosion protection Qualified for natural phenomena hazards such that containment is provided by either the primary or secondary pipe	Constructed of 6-in. schedule 40 carbon steel	

Table 3.7-8. Control Strategy Summary

Hazard Description: Guillotine Break of a Low Activity Waste Transfer Line				**Initiator:** Inadvertent Excavation Activity	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
BNFL Inc. excavation permit process	No associated SSC	To prevent inadvertent excavations in the vicinity of the LAW waste transfer lines To ensure that excavations intentionally conducted in the vicinity of the waste transfer lines are performed safely To identify emergency response actions	Administrative control, no associated design safety features	No applicable design assumptions	Consistent with or superior to existing Hanford Site excavation permit processes
Postings	Signposts and postings	To identify the transfer line route and alert individuals to the presence of an underground radioactive waste transfer line	Posting maintenance program that periodically surveys postings to verify condition	Designed to withstand extreme weather conditions	
Access control fencing	Fence	Prevent unauthorized access to the vicinity of the transfer lines	Access control program Posting maintenance program that periodically surveys postings to verify condition	Designed to withstand extreme weather conditions Access points sized to prevent access by mechanical digging equipment	

Table 3.7-8. Control Strategy Summary

Hazard Description: Guillotine Break of a Low Activity Waste Transfer Line				**Initiator:** Inadvertent Excavation Activity	
Selected Control Strategy	**Important-to-Safety SSCs**	**Safety Functions**	**Design Safety Features**	**Design Assumptions**	**Operational Assumptions**
Leak Detection	Leak detection system. To be determined during detailed design	To detect leakage of waste from the primary pipe to the secondary containment To automatically stop the transfer if a leak is detected	To be determined upon selection of a specific leak detection method Fail safe design, shut down of transfer pump on loss of electrical power to leak detection system Verification that the leak detection system is operable prior to performing a transfer	Leak detection to be interlocked to DOE waste transfer controls and leak detection system	Operator verification that pump has been de-energized

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[a] For access to these documents, contact the Design Safety Features Point-of-Contact through the office of Safety and Regulatory Programs, TWRS-P, Richland, Washington.

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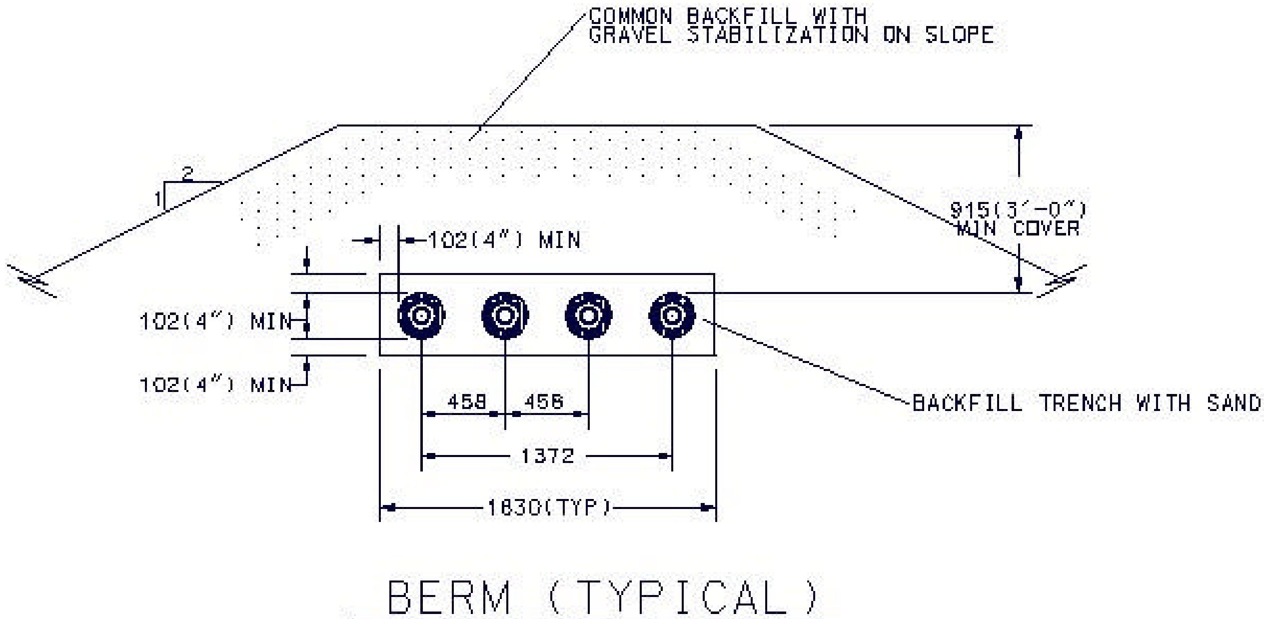
[b] Copies of these references accompany this deliverable.

Figure 3.7-1. Underground Coaxial Transfer Line Design Concept



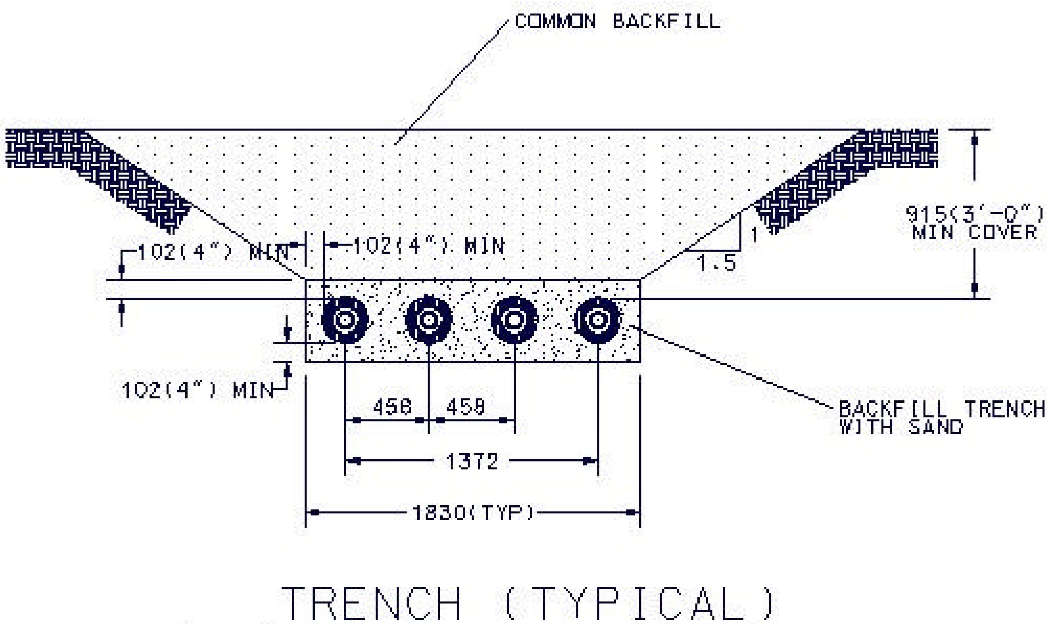


Figure 3.7-2. Tank 241-AP-106 Process Flow Diagram

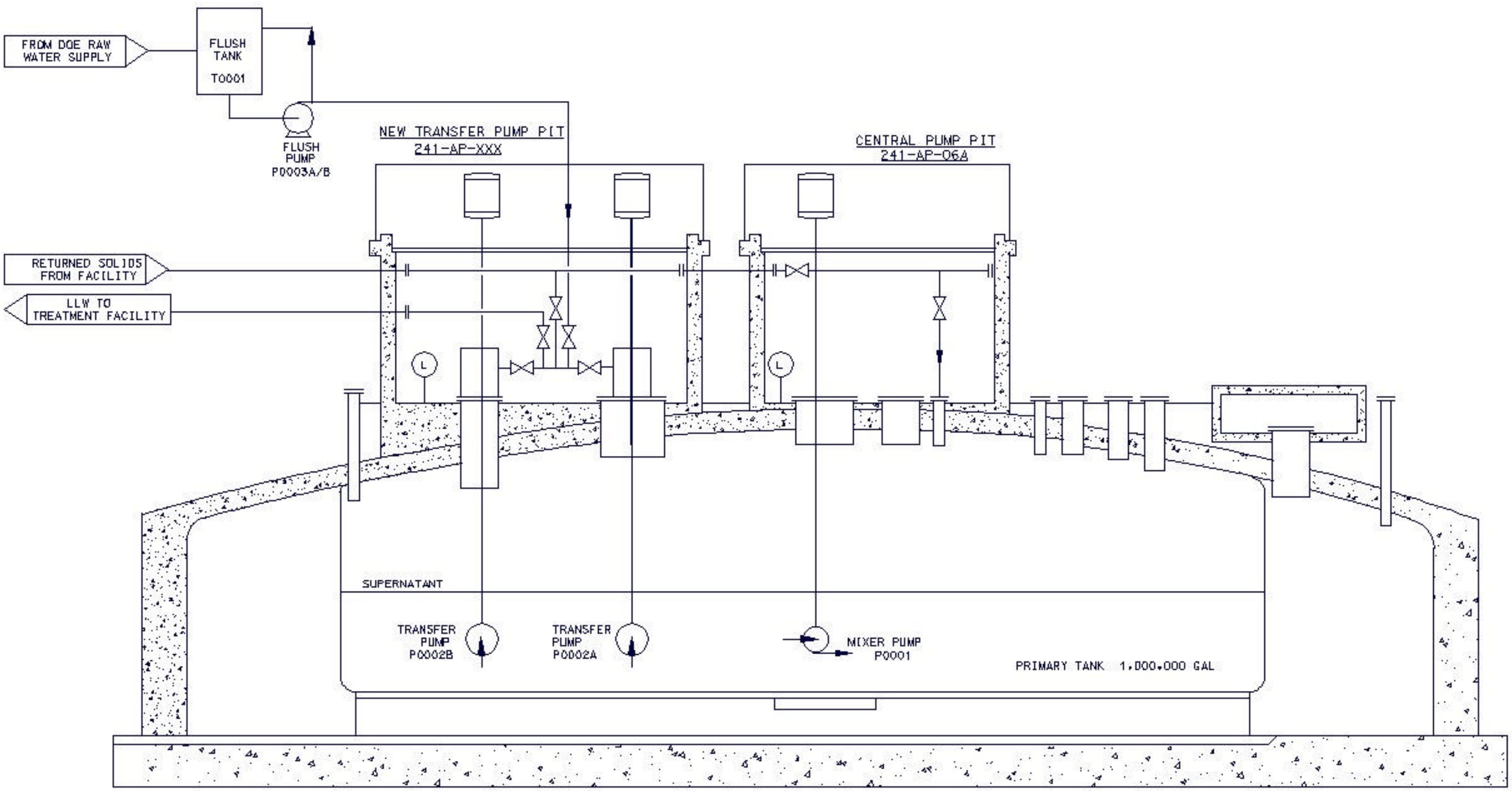


Figure 3.7-3. Low Activity Waste Evaporator Feed Vessels

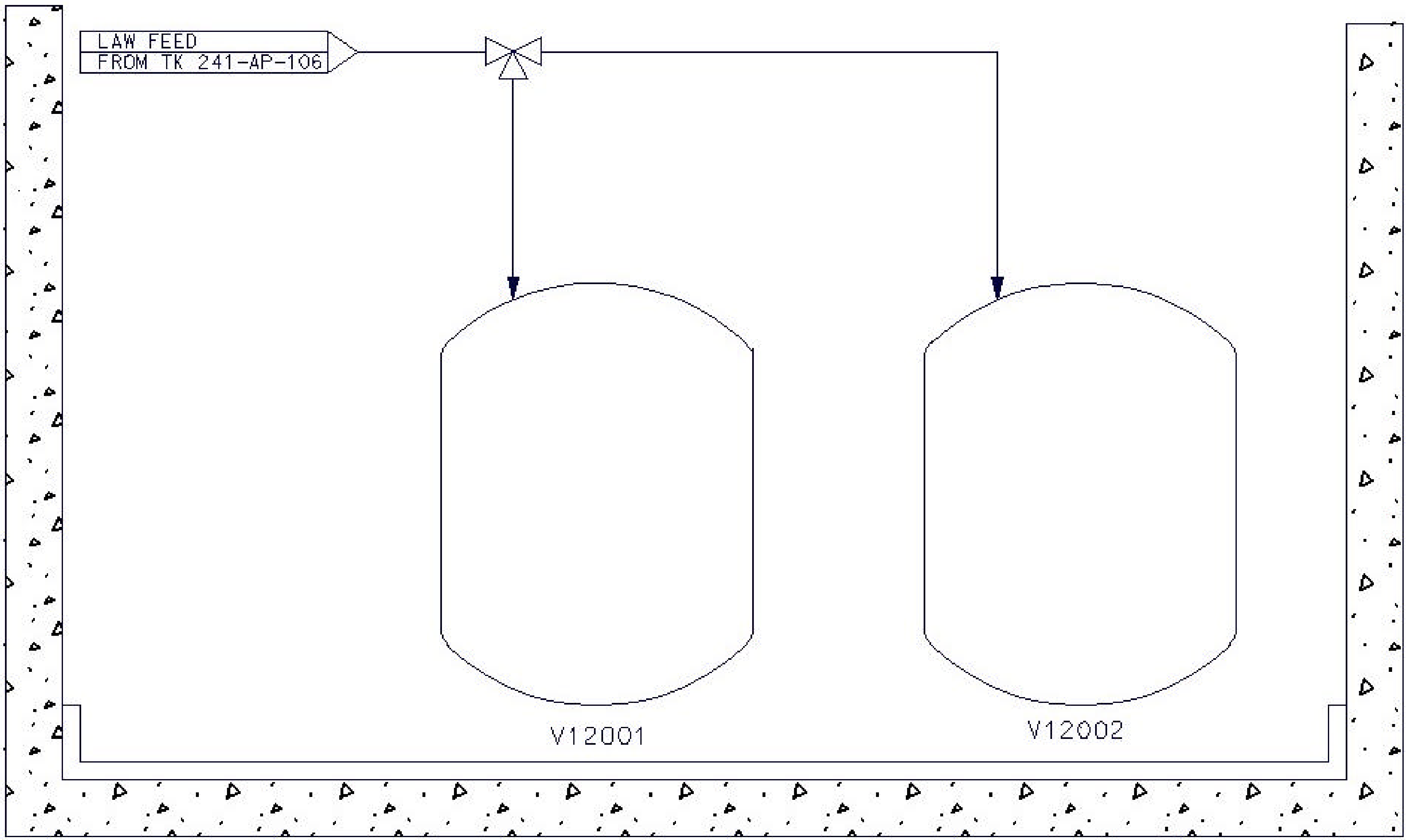


Figure 3.7-4. Low Activity Waste Transfer Line Route

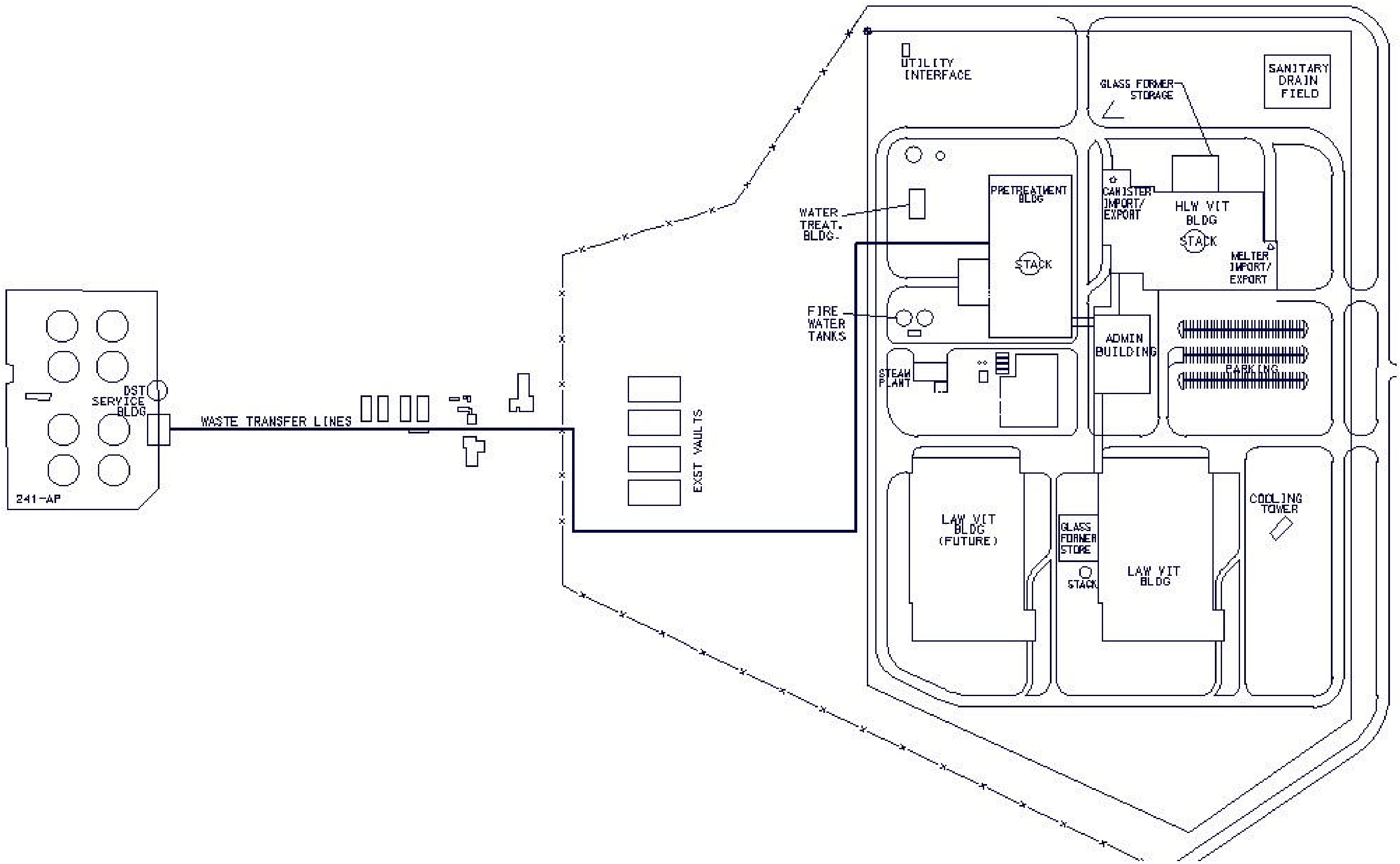


Figure 3.7-5. Low Activity Waste Transfer Line Elevation Diagram

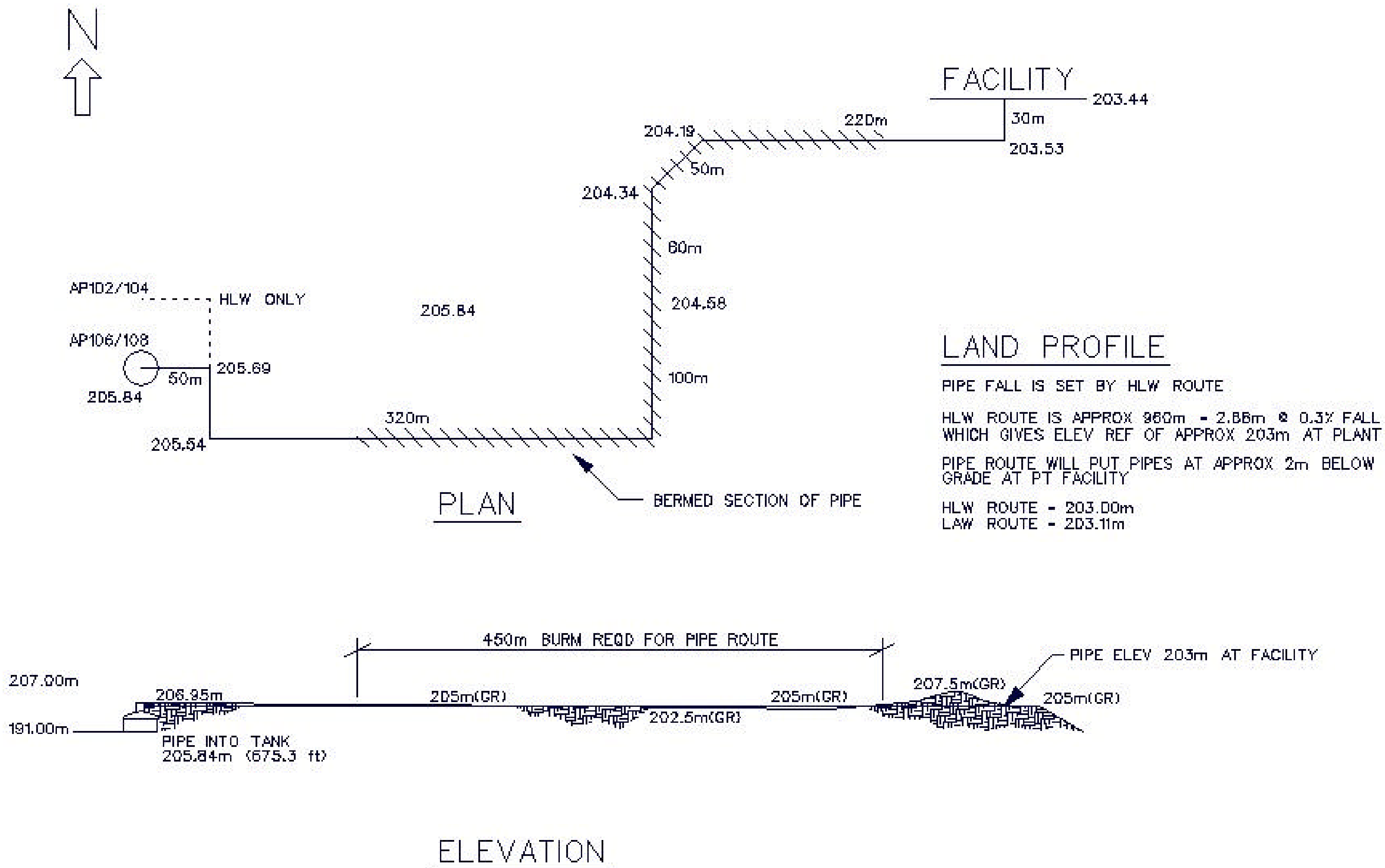


Figure 3.7-6. Hanford Site Excavation Permit

HANFORD SITE EXCAVATION PERMIT		EXCAVATION PERMIT NO.
1. Work Package No.	2. W.O./Project No.	3. Location of Excavation
4. Originated By — Date		5. Engineering Change Notice (*ECN*)
6. Drawings Required (*Identification Numbers*)		
7. Description of Work (*Attach composite drawing of excavation location and all know interferences*)		
8. Special Instructions or Comments (*Including safety requirements found in HNF-PRO-90 (or BHI-SI-01 10.3.3. as applicable) and applicable company-specific procedure*)		
9. List Facilities, Services, and Utilities Affected by Excavation		

APPROVALS			
10. Project Engineer	Date	18. Traffic Engineer	Date
11. Environmental	Date	19. Track Maintenance	Date
12. Radiological Control	Date	20. 600 Area Landlord	Date
13. Steam-ESPC	Date	21. Safeguards and Security	Date
14. Electrical Utilities	Date	22. Land Use Planning	Date
15. Water Utilities	Date	23. Other	Date
16. Telecommunications	Date	24. Facility/System Owner/Cognizant Engineer (*Last Signature*)	Date
17. Process Sewer - 300 Area	Date		

Locate Request No. ____________

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